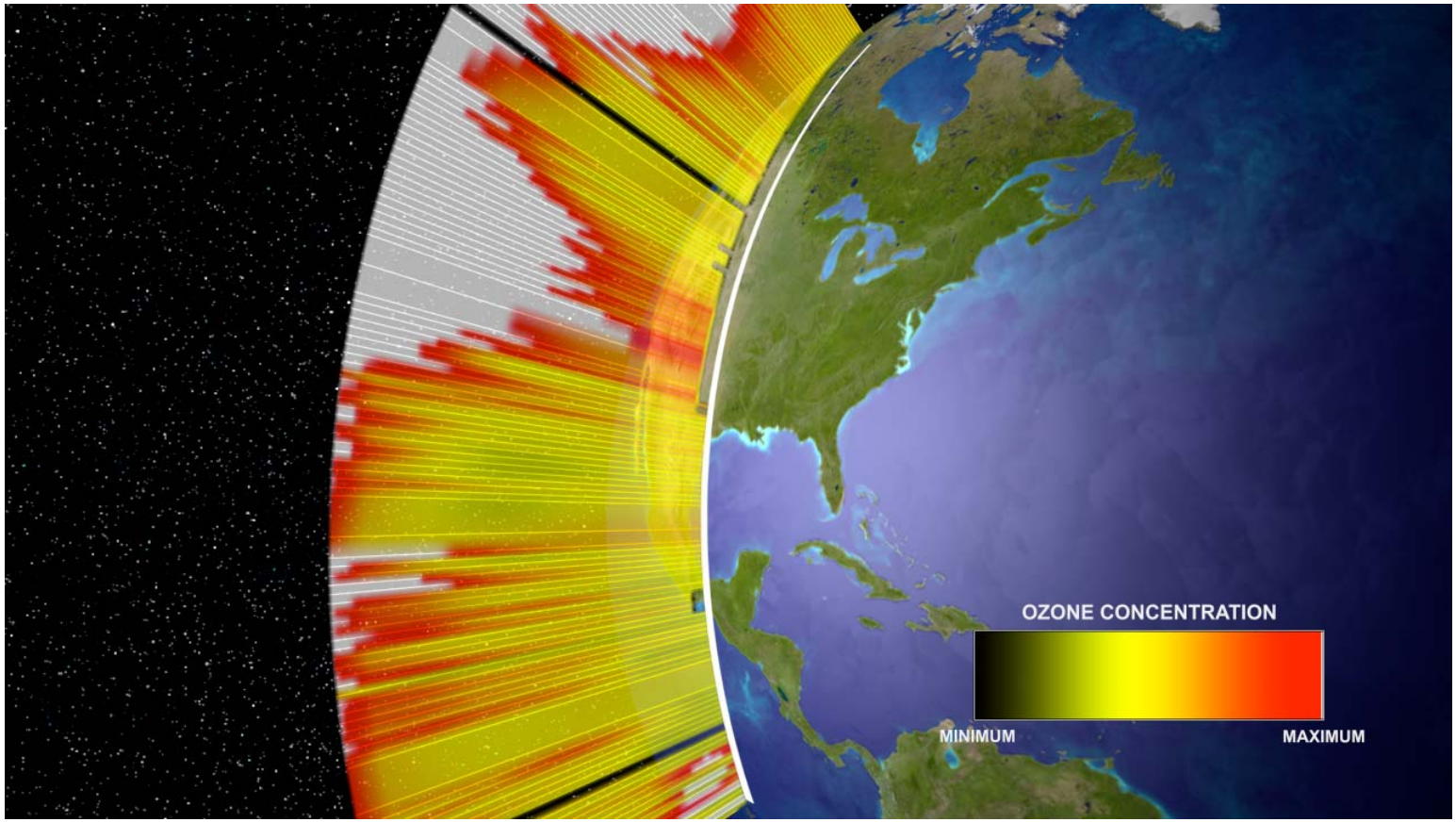
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

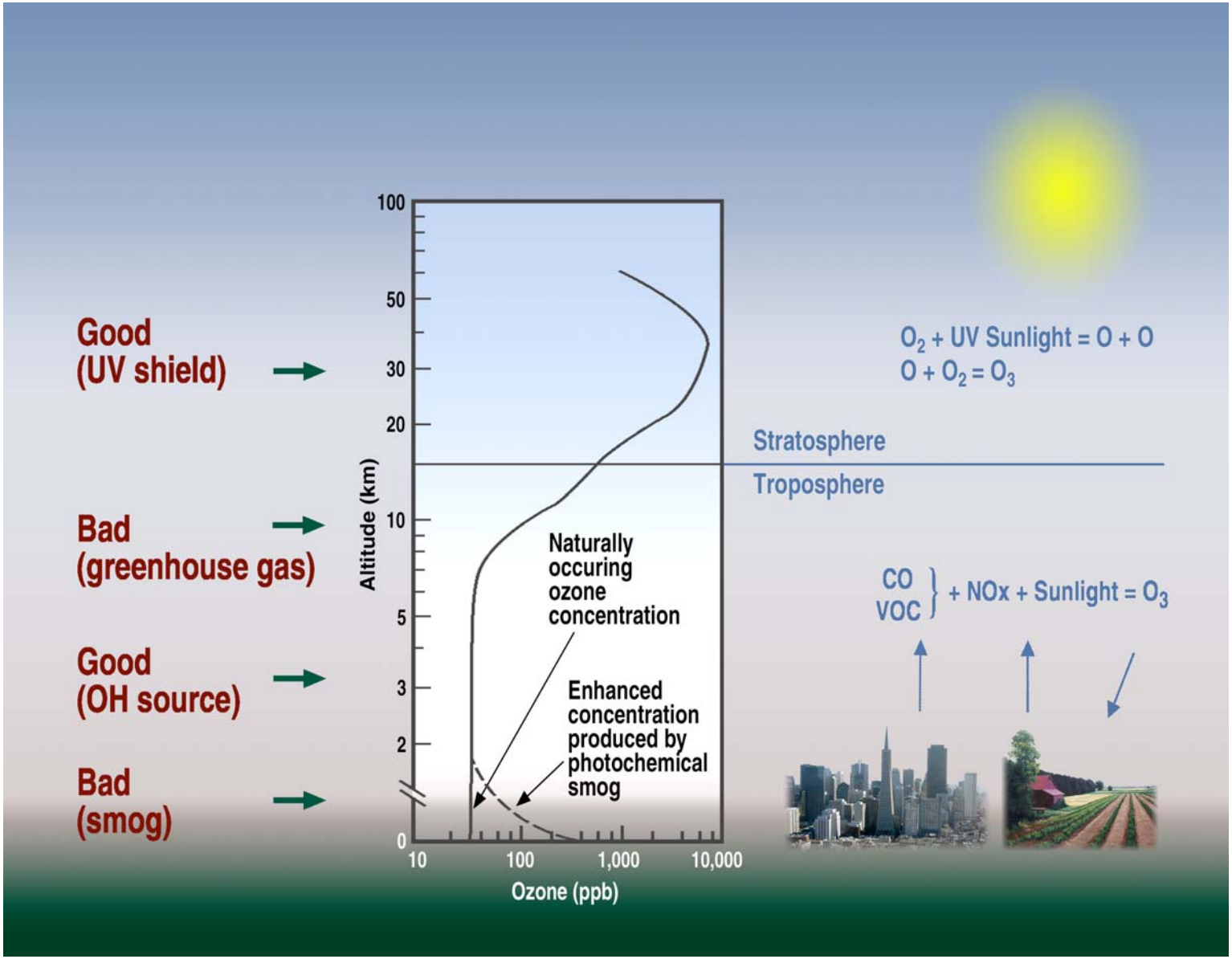
Tropospheric Emission Spectrometer

TES: Probing Global Air Quality from Space



Annmarie Eldering and TES Science Team,
JPL/Caltech

The vertical distribution of ozone



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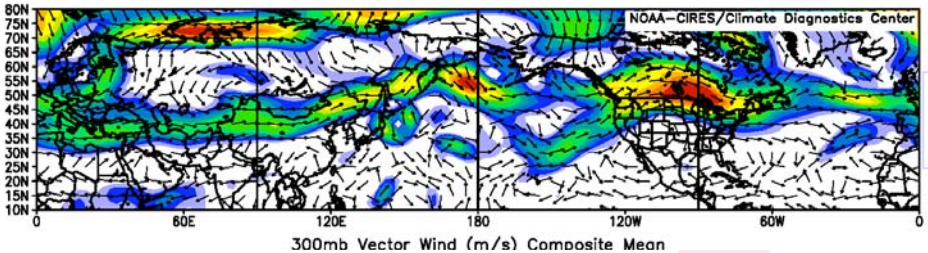
Tropospheric Emission Spectrometer

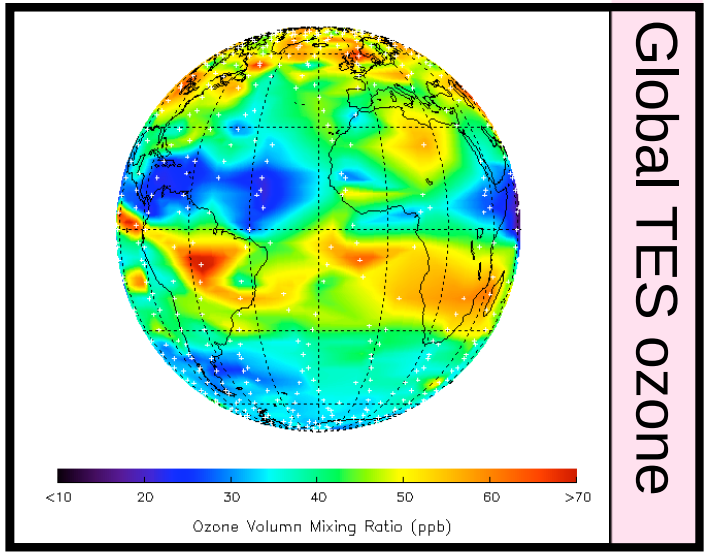
Tropospheric ozone is a complex problem!

Anthropogenic sources

Natural precursors



Advection



Solar radiation

Convection

Subsidence

Tropospheric Emission Spectrometer

TES on EOS-Aura

Launched 2004.07.15

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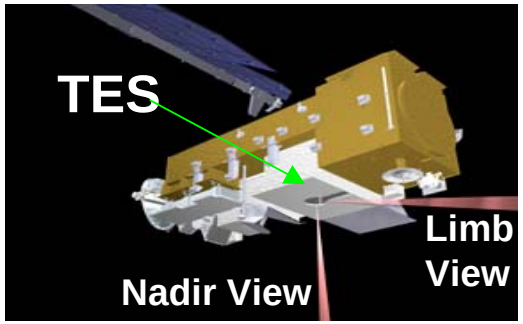
Tropospheric Emission Spectrometer

TES Instrument Specifications



http://tes.jpl.nasa.gov

Spectrometer Type	Connes'-type 4-port Fourier Transform Spectrometer
Max. Optical Path Difference	± 8.45 cm (normal) ± 33.8 cm (hi-res); interchangeable
Scan (integration) Time	4 sec (normal) 16 sec (hi-res)
Sampling Metrology	Nd:YAG laser
Spectral Resolution (unapodized)	0.06 cm^{-1} (normal) 0.015 cm^{-1} (hi-res)
Spectral Coverage	650 to 3050 cm^{-1} (3.2 to 15.4 um)
Detector Arrays	4 (1 x 16) arrays, optically-conjugated, all MCT PV @65K
Field of Regard	45° cone about nadir; trailing limb or cold space; internal calibration sources
Pointing Accuracy	75 urad pitch, 750 urad yaw 1100 urad roll
Max. Stare Time,	208 sec (40 nadir scans)
Spatial Resolution	0.5 x 5 km (nadir) 2.3 x 23 km (limb)
Radiometric Calibration	cavity blackbody (340K) + cold space view
Detector Array Co- alignment	Internal thin slit calibration source
Nadir NESR (Noise Equivalent Spectral Radiance)	2B1 filter: 700 $nW/cm^2/sr/cm^{-1}$ 1B2 filter: 200 2A1 filter: 150 1A1 filter: 100
Nadir NEDT @290K (Noise Equivalent Delta Temperature)	2B1: 1.08 K for 16 detector average 1B2: 0.36 K for 16 detector average 2A1: 0.36 K for 16 detector average 1A1: 2.07 K for 15 detector average

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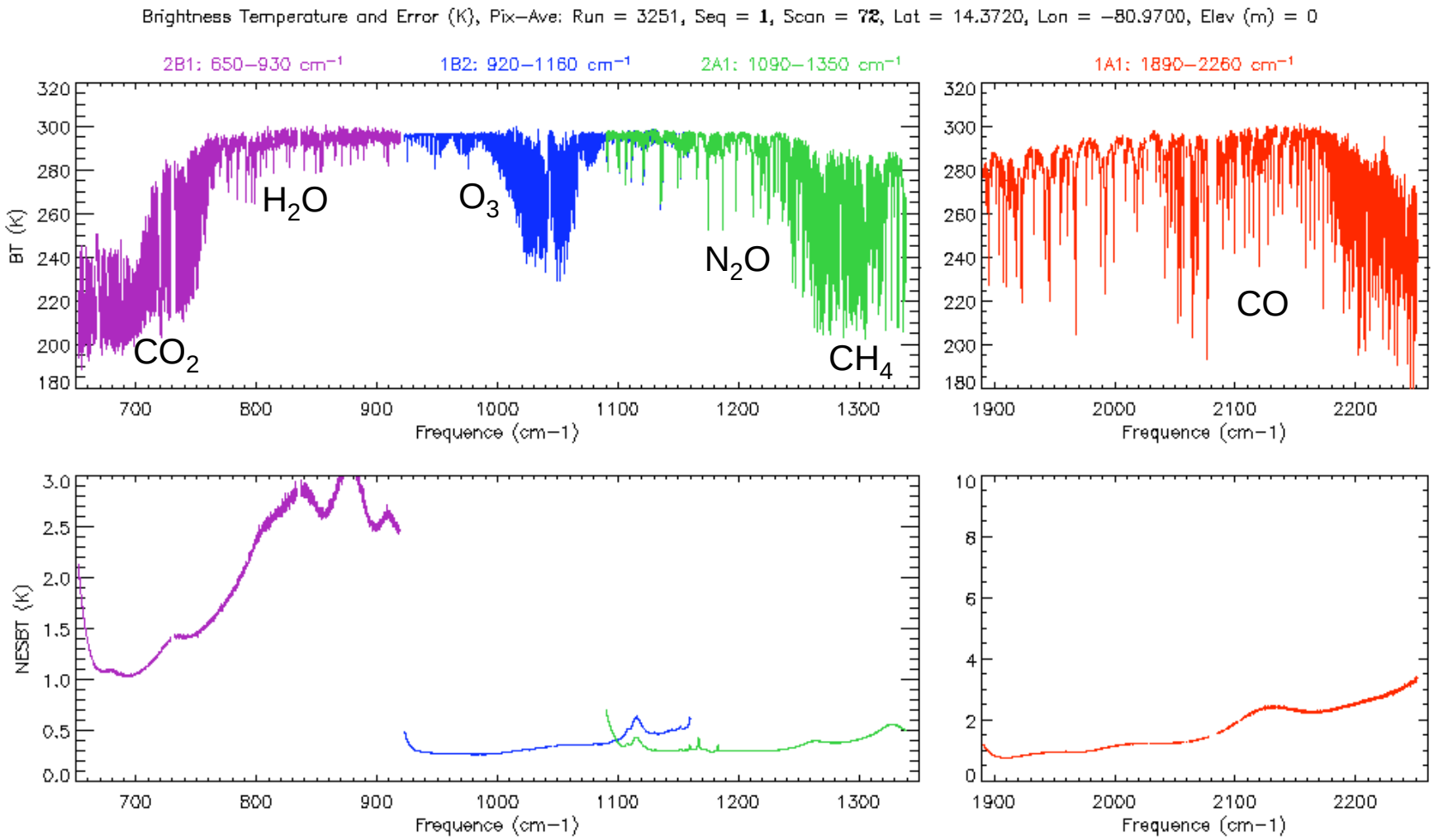
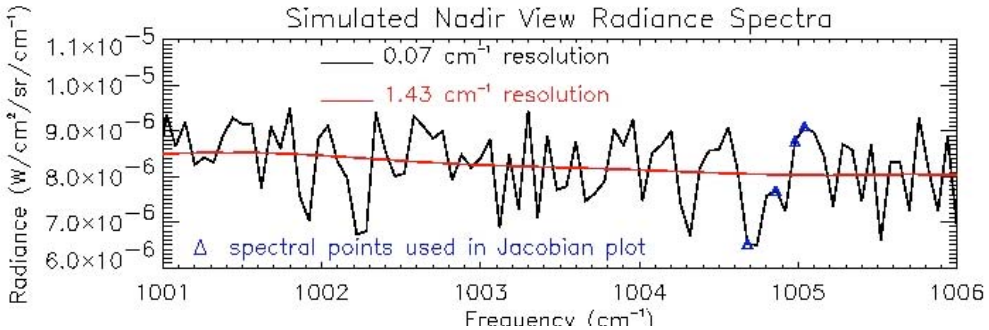
Tropospheric Emission Spectrometer

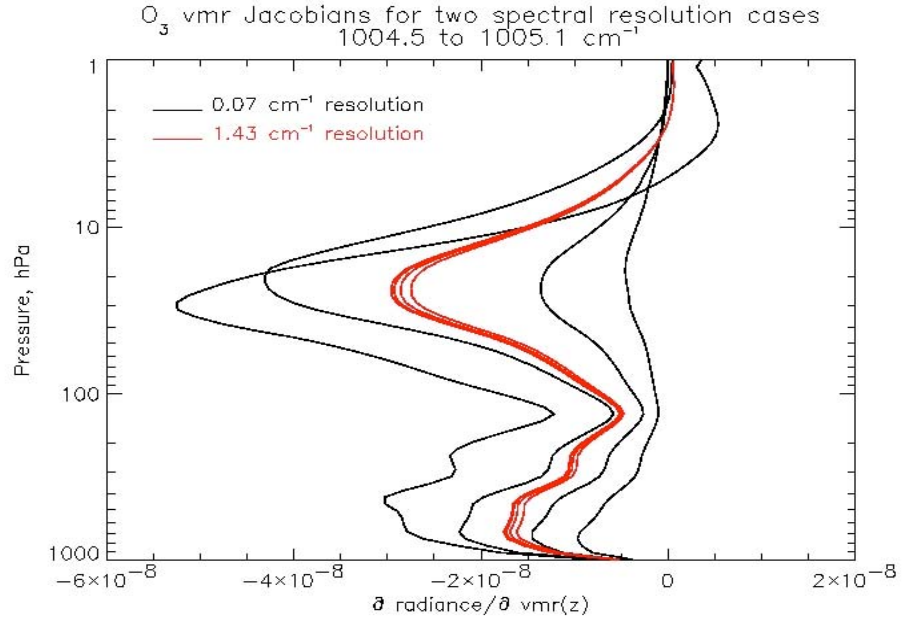
TES spectra and noise

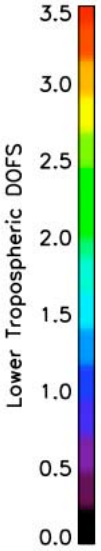


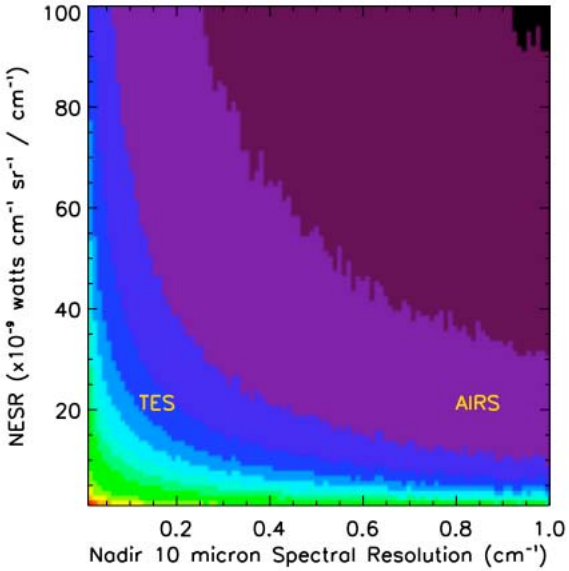
Tropospheric Emission Spectrometer

It's the spectral resolution!









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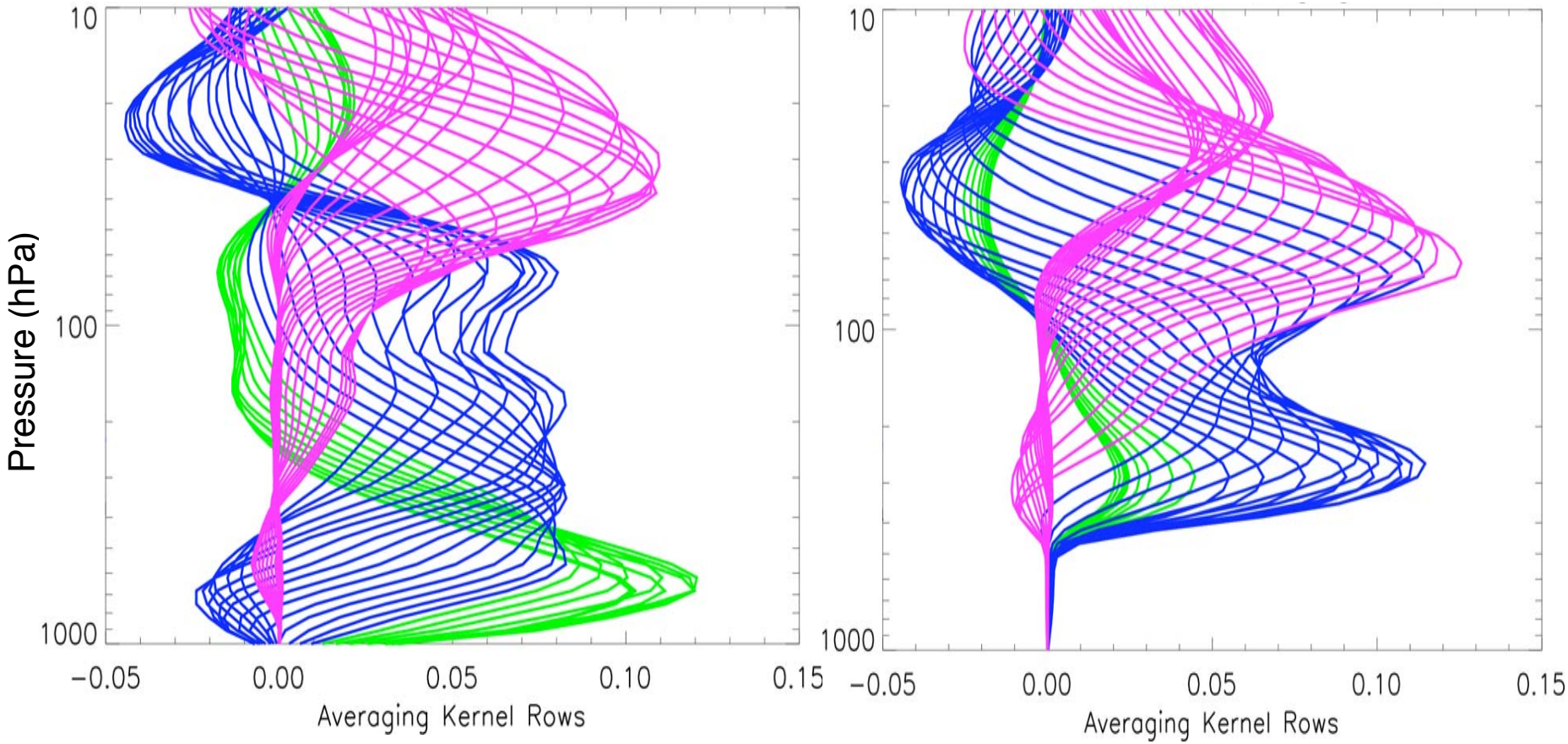
Averaging Kernels for Ozone



Clear (DOFS = 4.1)

Cloud at 483 hPa (DOFS = 3.0)

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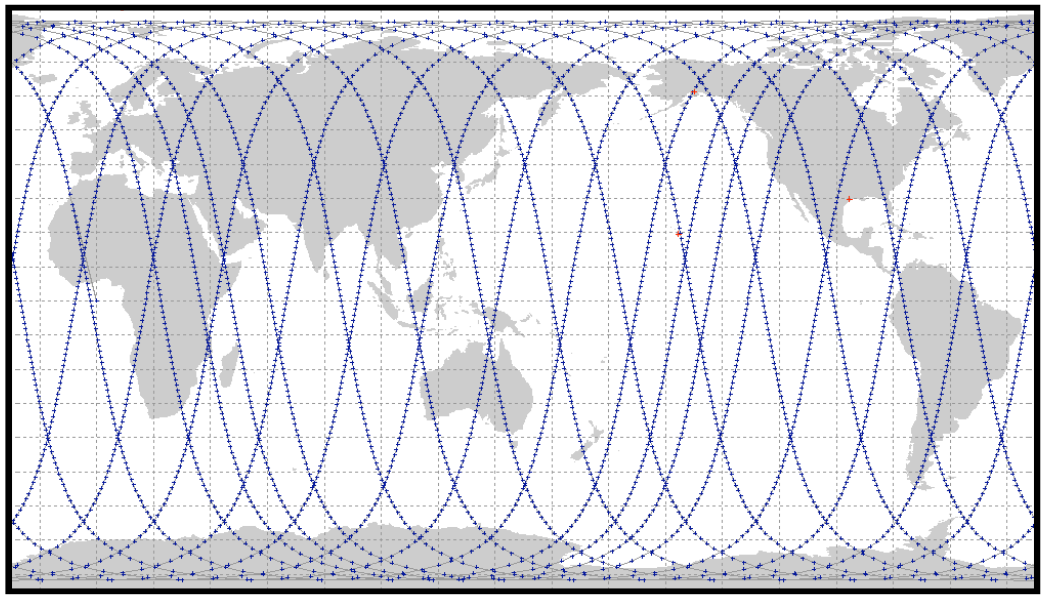
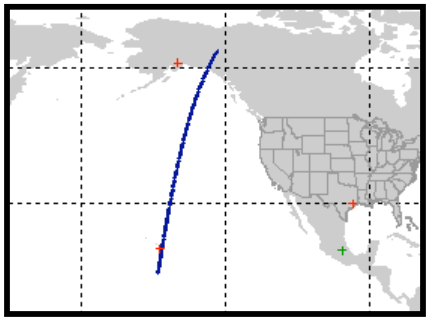
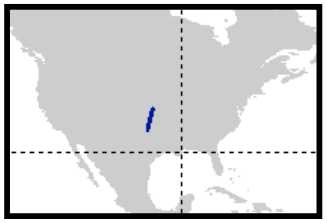
Examples of TES nadir coverage

Global Survey footprints
180 km apart
Every 2 days… 312 and counting



Step/Stare footprints
45 km apart
Special observation





Transect footprints
Contiguous!
Special observation

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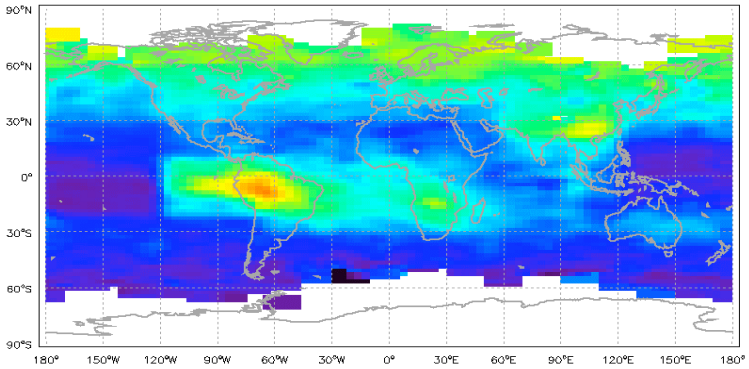
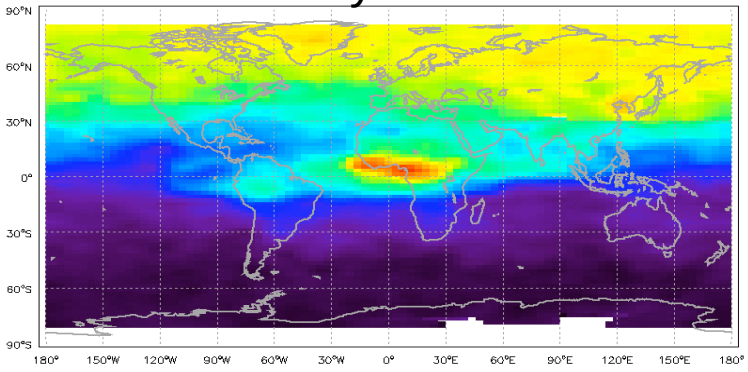
Tropospheric Emission Spectrometer

TES CO Monthly Means at 681.3 hPa

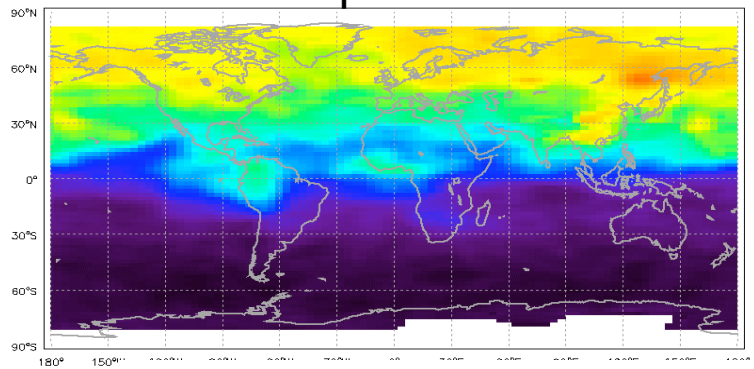
October 2005



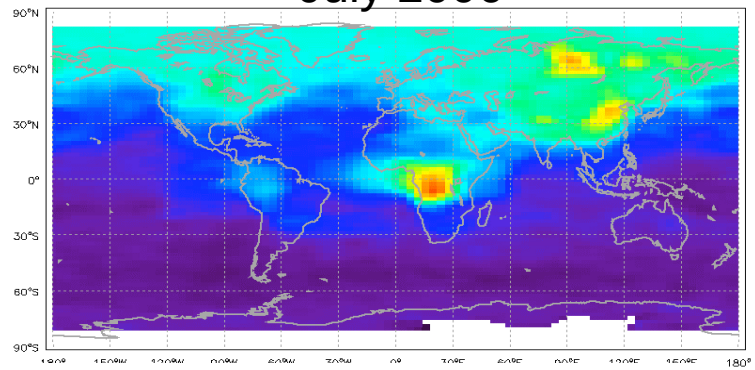
January 2006

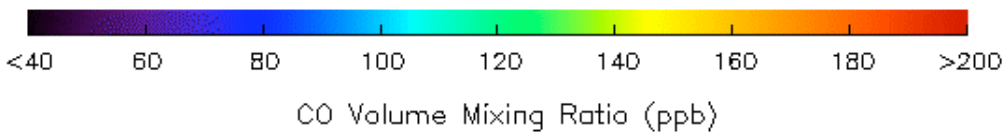


April 2006



July 2006





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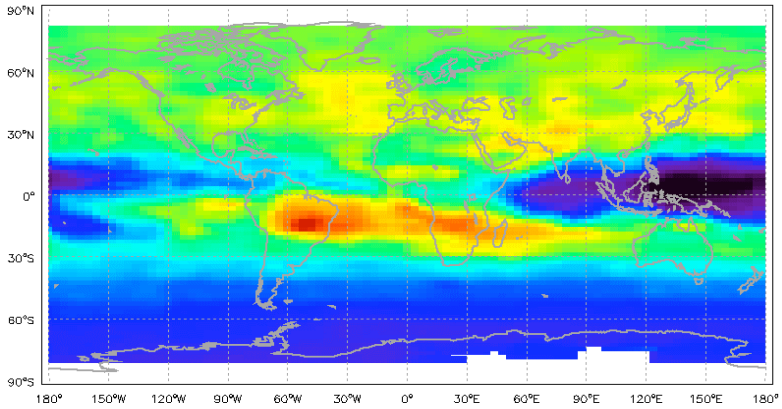
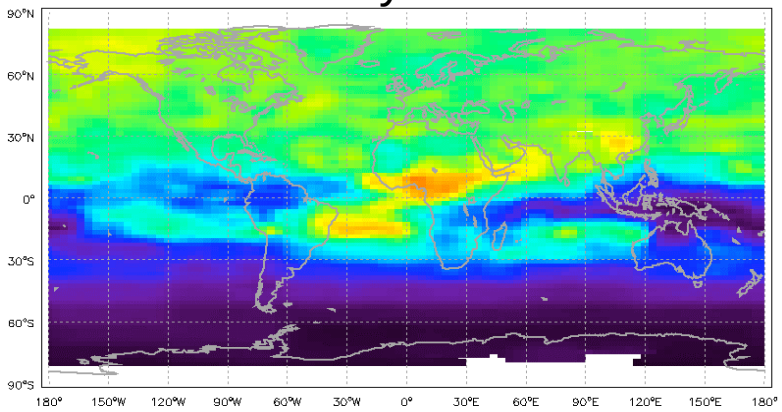
Tropospheric Emission Spectrometer

TES Ozone Monthly Means at 681.3 hPa

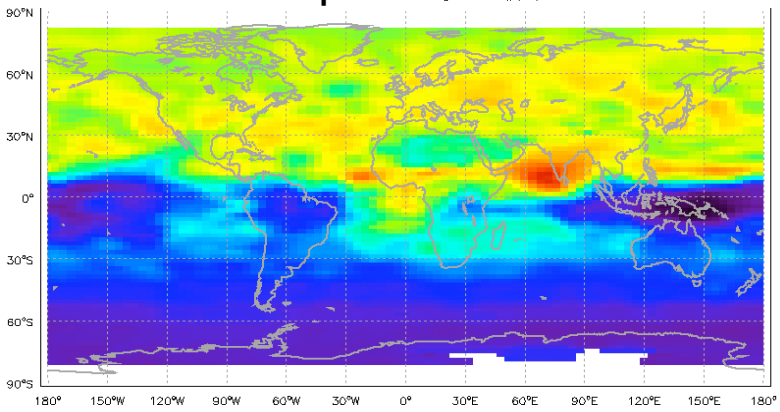
October 2005



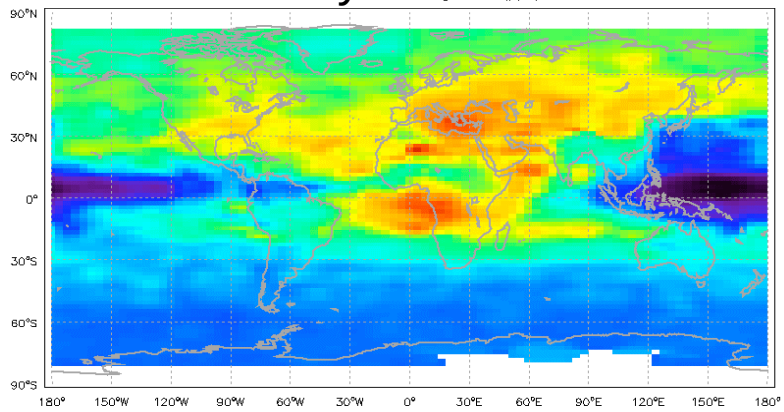
January 2006

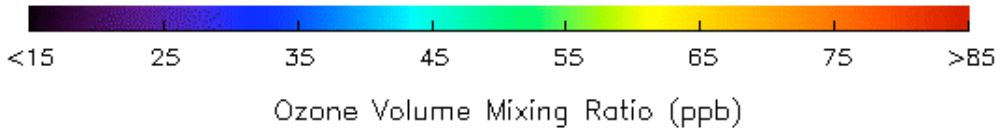


April 2006



July 2006





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Tropospheric Emission Spectrometer

Validation Status

Species	Validation Status
Nadir Ozone	Validated
Nadir Carbon Monoxide	Validated
Nadir Water	Provisionally Validated
Nadir Temperature	Provisionally Validated
Surface Temperature	Provisionally Validated
Nadir HDO	Provisionally Validated
Nadir Methane	Not Validated (2007)
Limb Nitric Acid	Not Validated (2007)
Limb Ozone	Not Validated (2007)
Limb Temperature	Not Validated (2007)

All data are at the Langley DAAC
http://eosweb.larc.nasa.gov/PRODOCS/tes/table_tes.html
as of 12/2006, 312 Global Surveys & 717 Special Observations

Recent TES Papers

National Aeronautics and Space Administration
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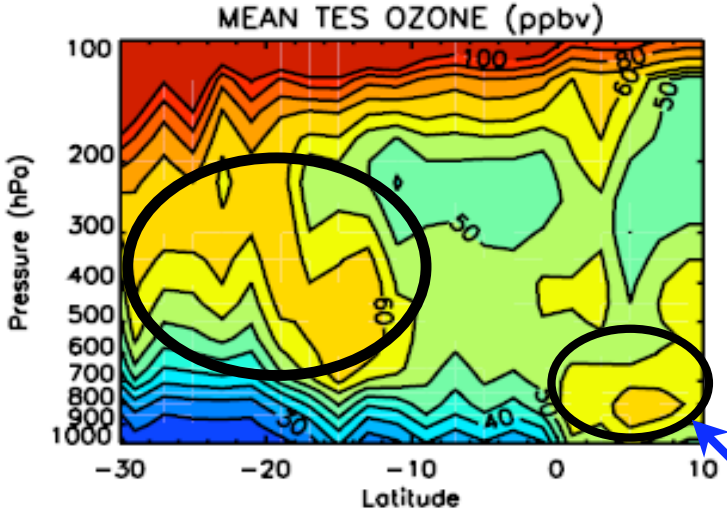
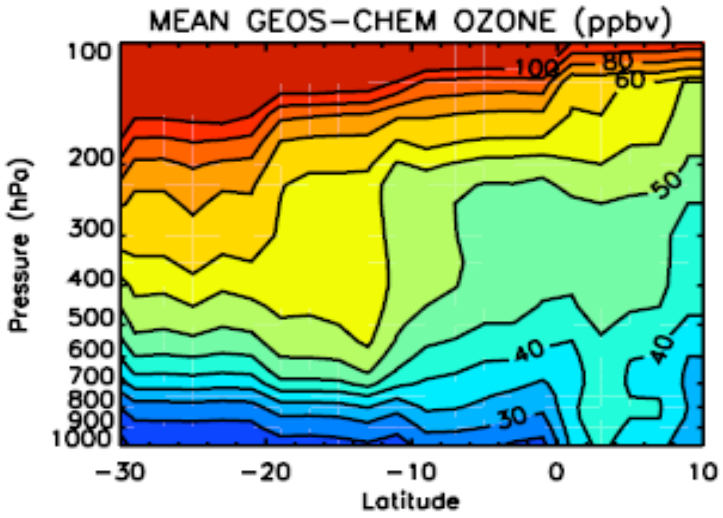
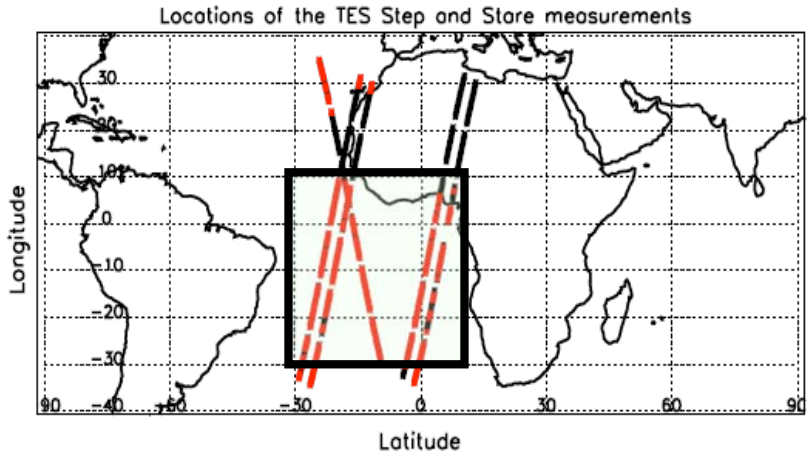
California Institute of Technology

Tropospheric Emission Spectrometer

"Tropospheric vertical distribution of tropical Atlantic ozone observed by TES during the Northern African biomass burning season"







For the first time, elevated ozone in the lower troposphere has been *directly* measured for 0° – 10° N over the tropical Atlantic Ocean.

L. Jourdain, H. M. Worden *et al.*, (2007) GRL

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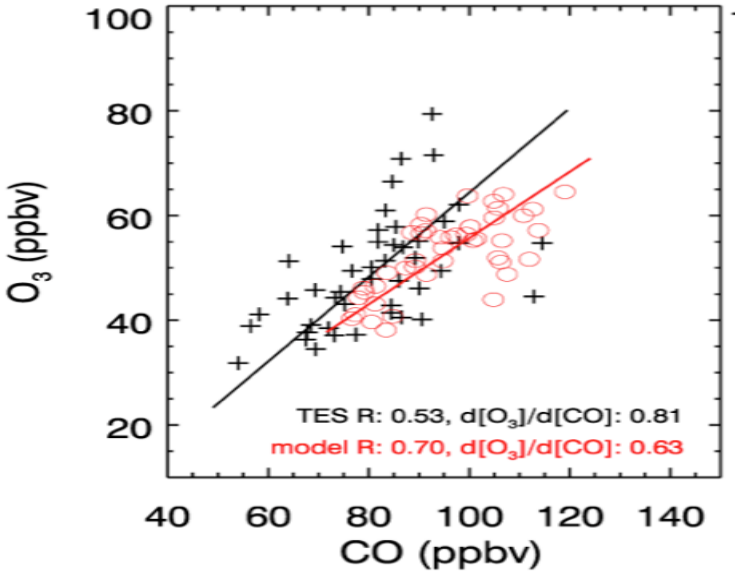
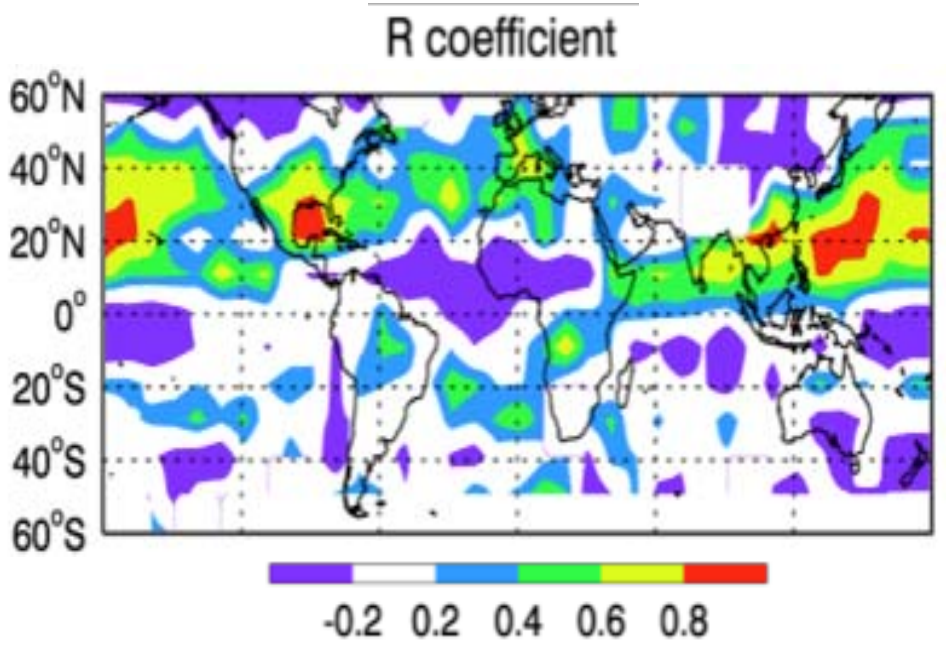
"Continental outflow of ozone pollution as determined by O3-CO correlations from the TES satellite instrument"





Studying the influence of anthropogenic pollution

- Ozone and CO correlations are high downwind of polluted continents, and allow tests of global model simulations.

L. Zhang, D. Jacob, *et al.,* (2006) GRL article and press release

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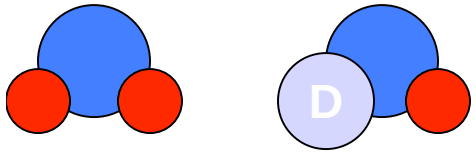
Tropospheric Emission Spectrometer

"Importance of rain evaporation and continental convection in the tropical water cycle"

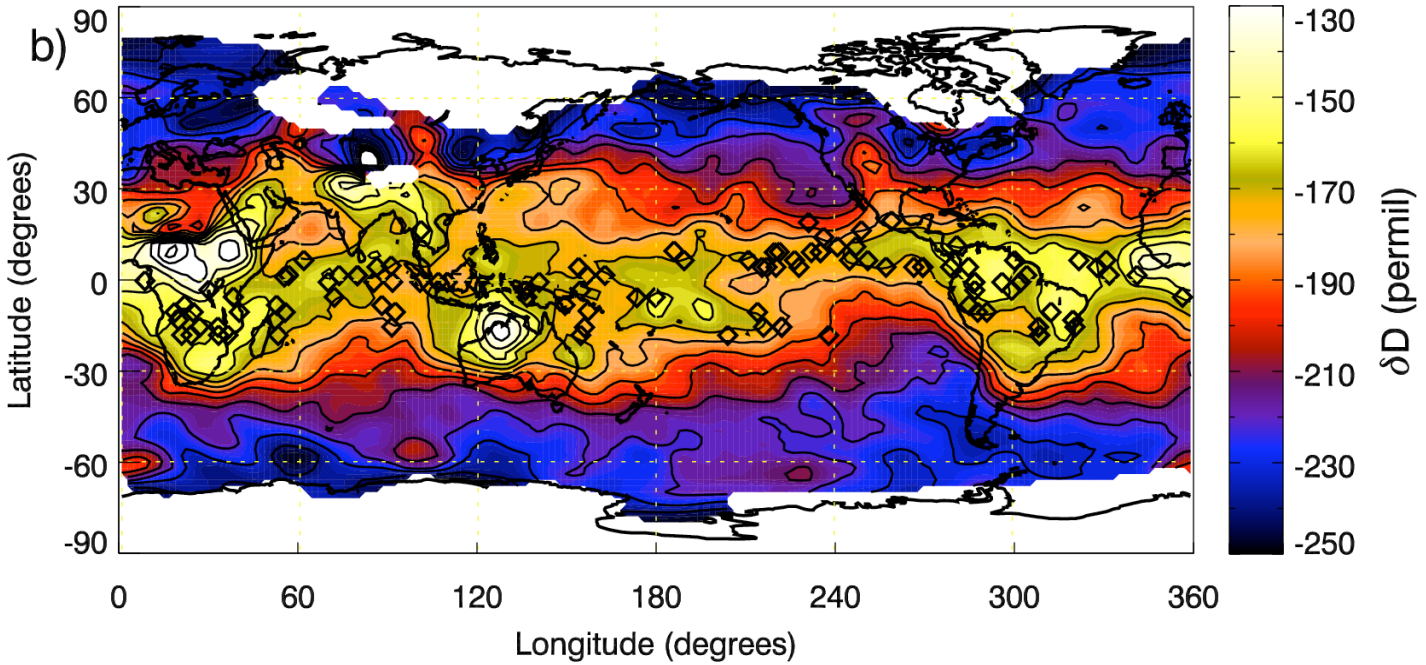


H_2O HDO

TES HDO

(~700 hPa)

50 days
Oct 05 –
Mar 06)



Water isotopes identify and quantify "hidden" water sources

- Rainfall evaporation an important rehydration mechanism in tropics
- Direct observation of evapo-transpiration as a tropical water source

J. Worden, D. Noone, K. Bowman, *et al.*, *Nature* 445, 528 - 532 (01 Feb 2007)

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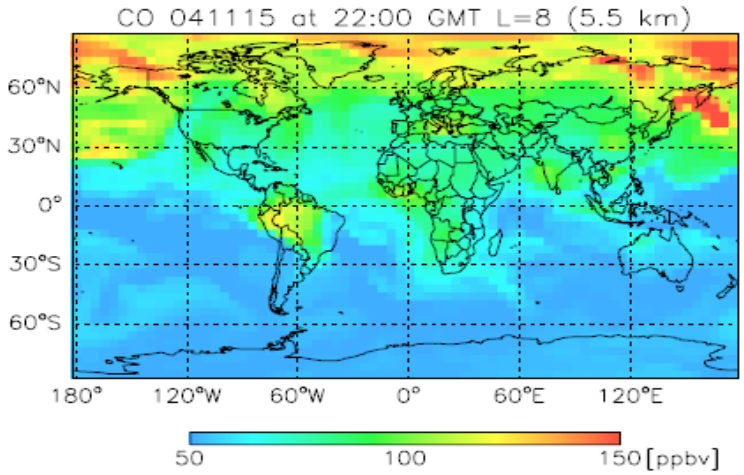
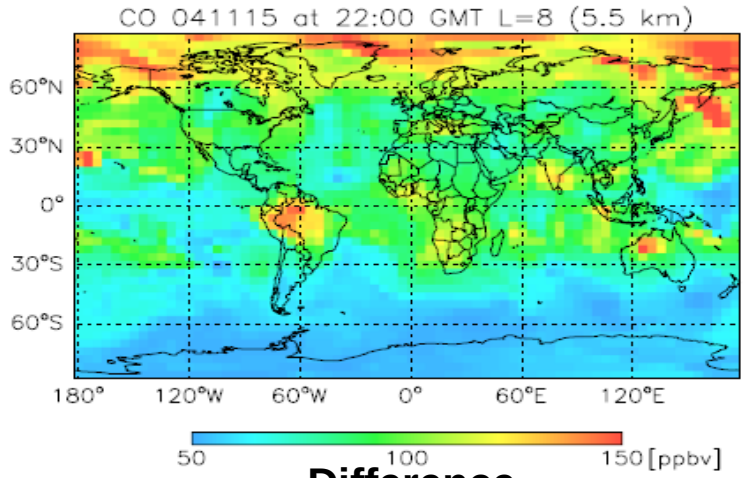
Tropospheric Emission Spectrometer

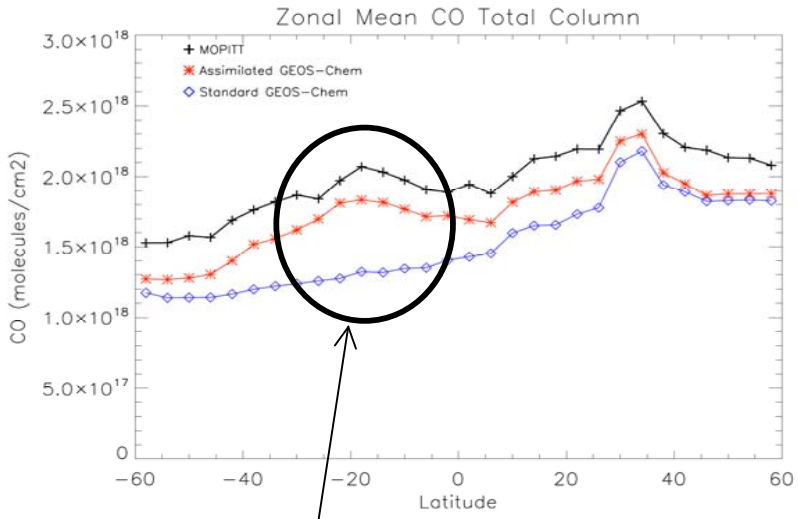
"Assimilation of TES CO into a global CTM: First results"

GEOS-Chem without TES assimilation

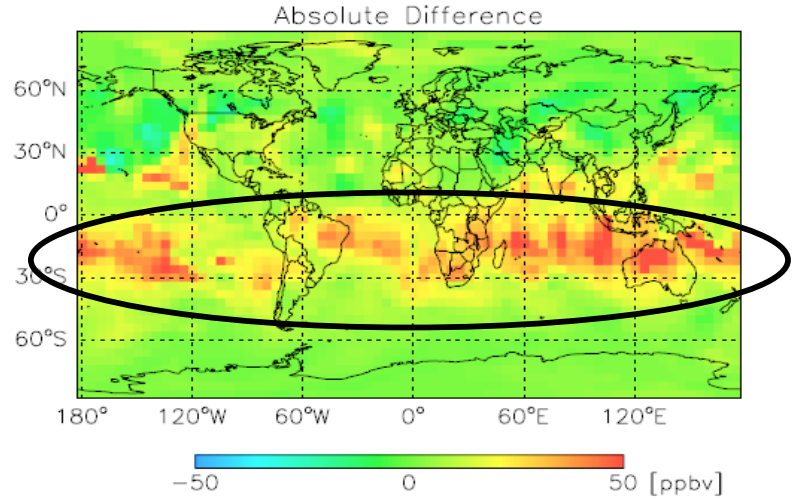


GEOS-Chem with TES assimilation





Difference



Dramatic improvement to comparison of GEOS-Chem to MOPITT after assimilating TES CO.

N. Richards, Q. Li, *et al*., (2006), ACPD, in press.

Recent TES Results

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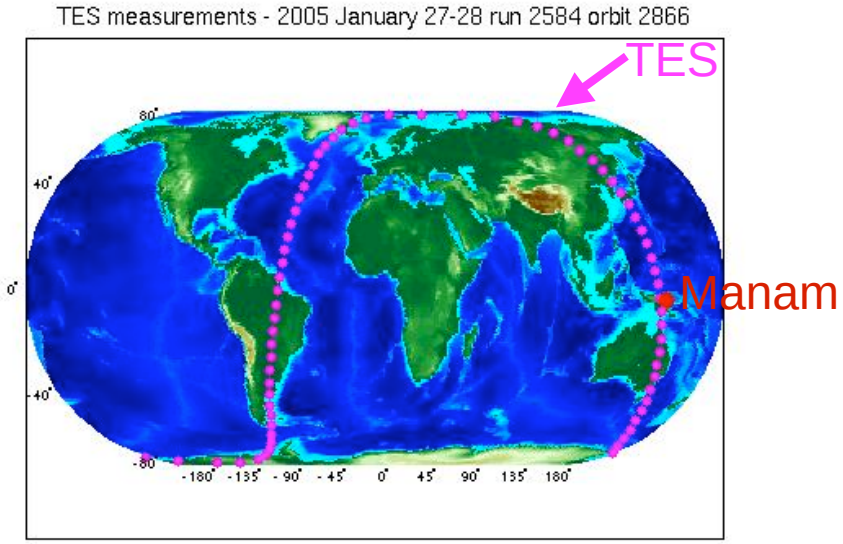
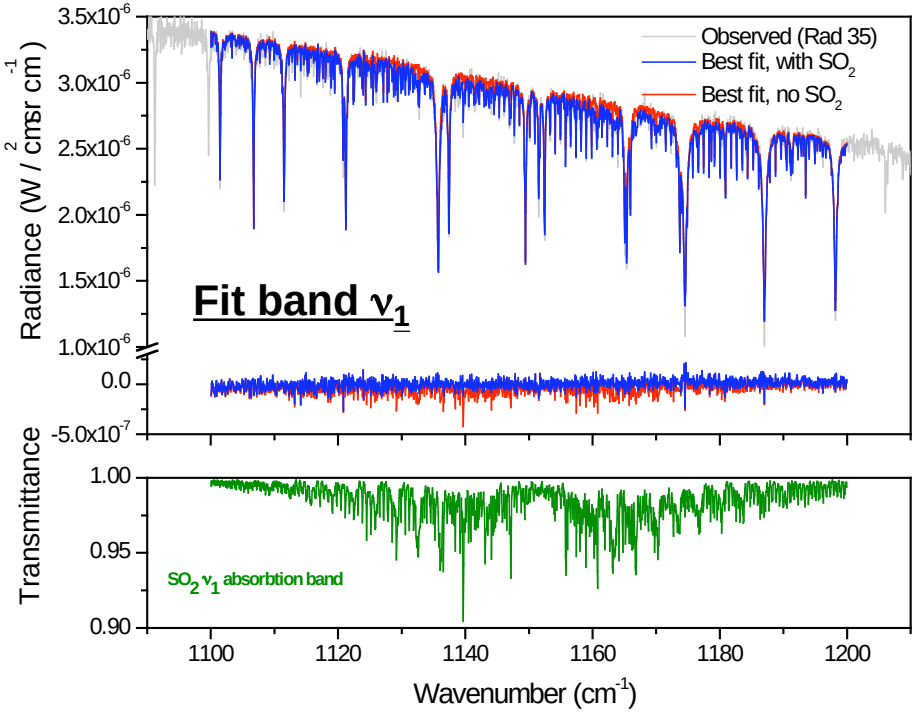
Tropospheric Emission Spectrometer

Retrieval of Volcanic SO2 using TES Spectra

Cathy Clerbaux, Service d'Aeronomie/CNRS
Pierre Coheur, Université Libre de Bruxelles





IASI team was interested in demonstrating detection and retrieval of SO_2 with TES data.

Applied optimal estimation to retrieve SO_2 using TES retrieval results for clouds and primary atmospheric profiles (T, H_2O, O_3)

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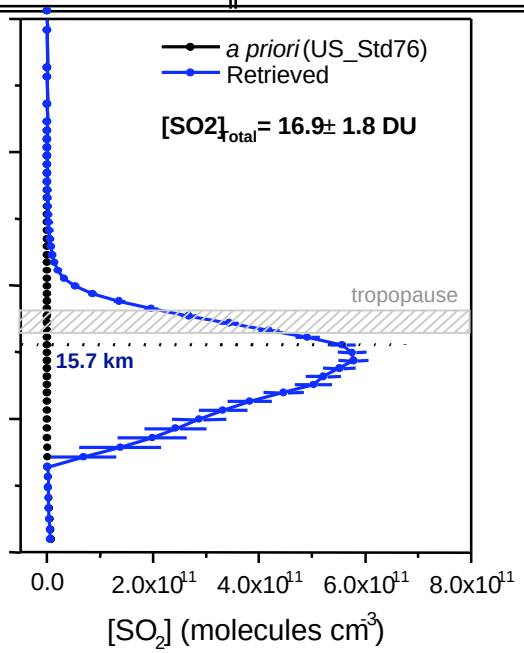
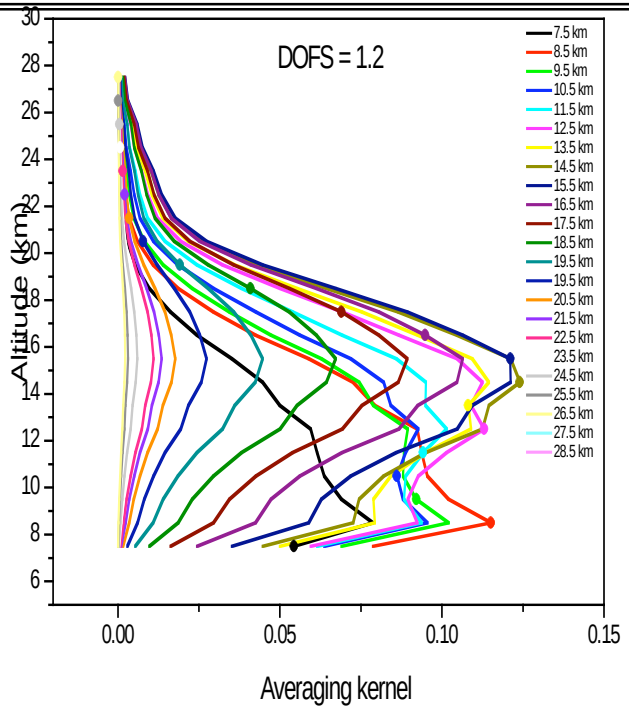
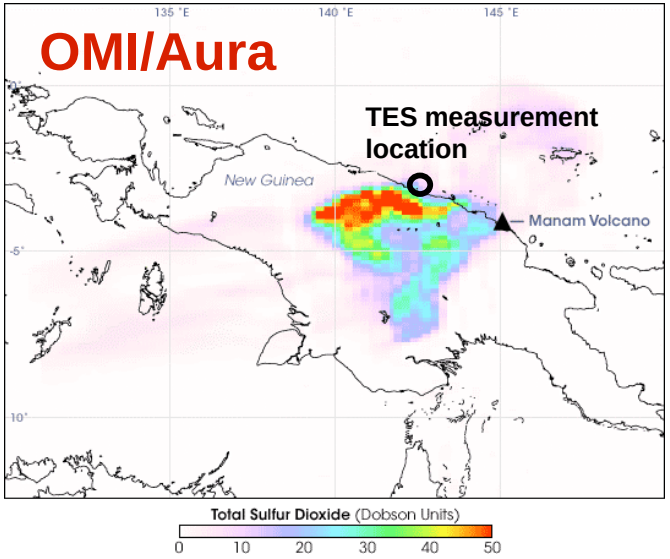
Tropospheric Emission Spectrometer

Optimal estimation to retrieve SO_2







- Sulfur dioxide plume from Manam volcano eruption January 27, 2006
- Aura closest aproach January 28, 2006
- TES footprint at 3.4°S, 142.2°E
  - Thick cloud retrieved around 430 hPa.
- TES and OMI SO_2 columns near plume edges are both ~17 DU.

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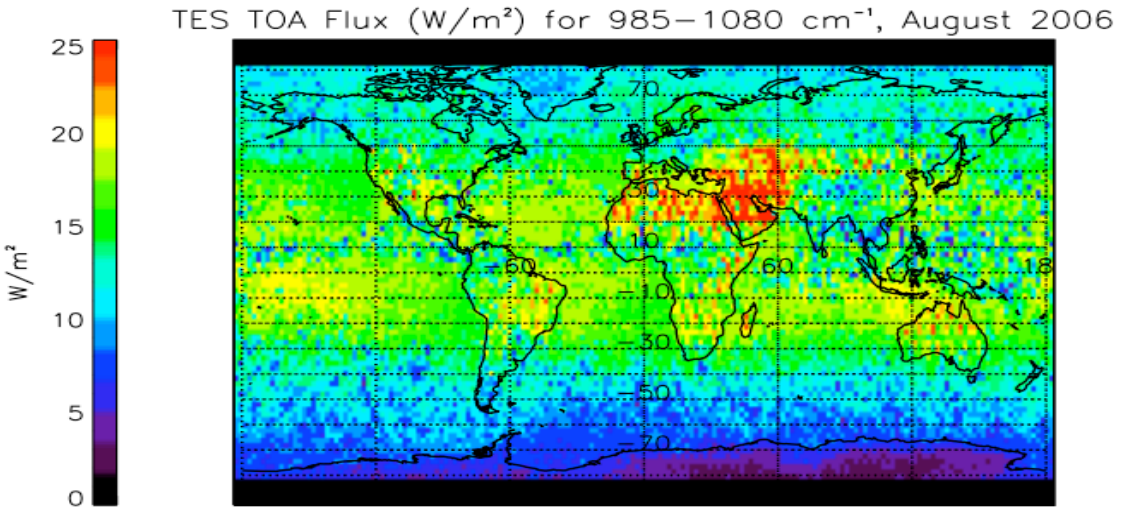
Tropospheric Emission Spectrometer

OLR in the O3 band - relationship to vertical distribution of ozone

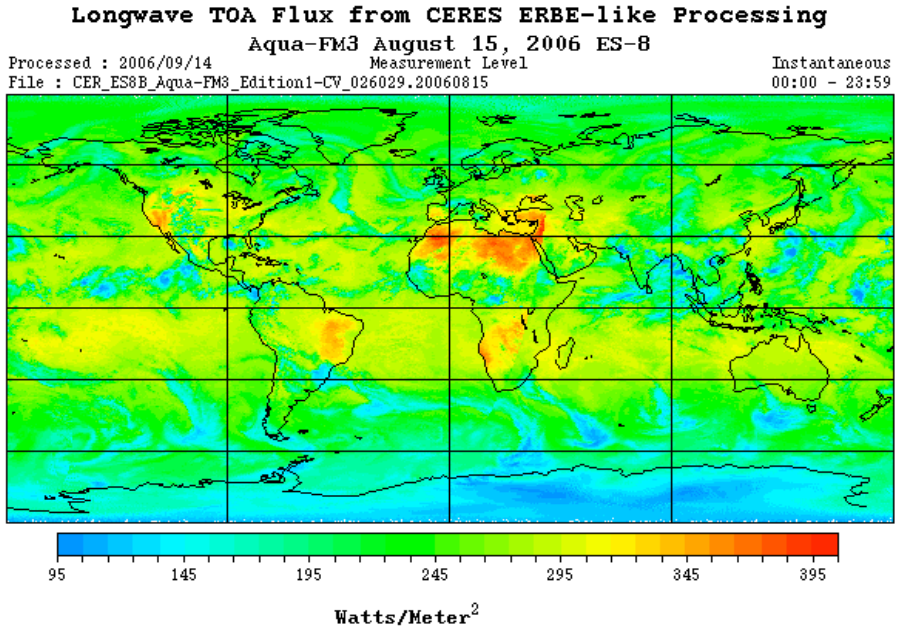
TES

TOA flux for
985-1080 cm^{-1}
Aug 2006



CERES

Longwave TOA flux
Aug 15, 2006



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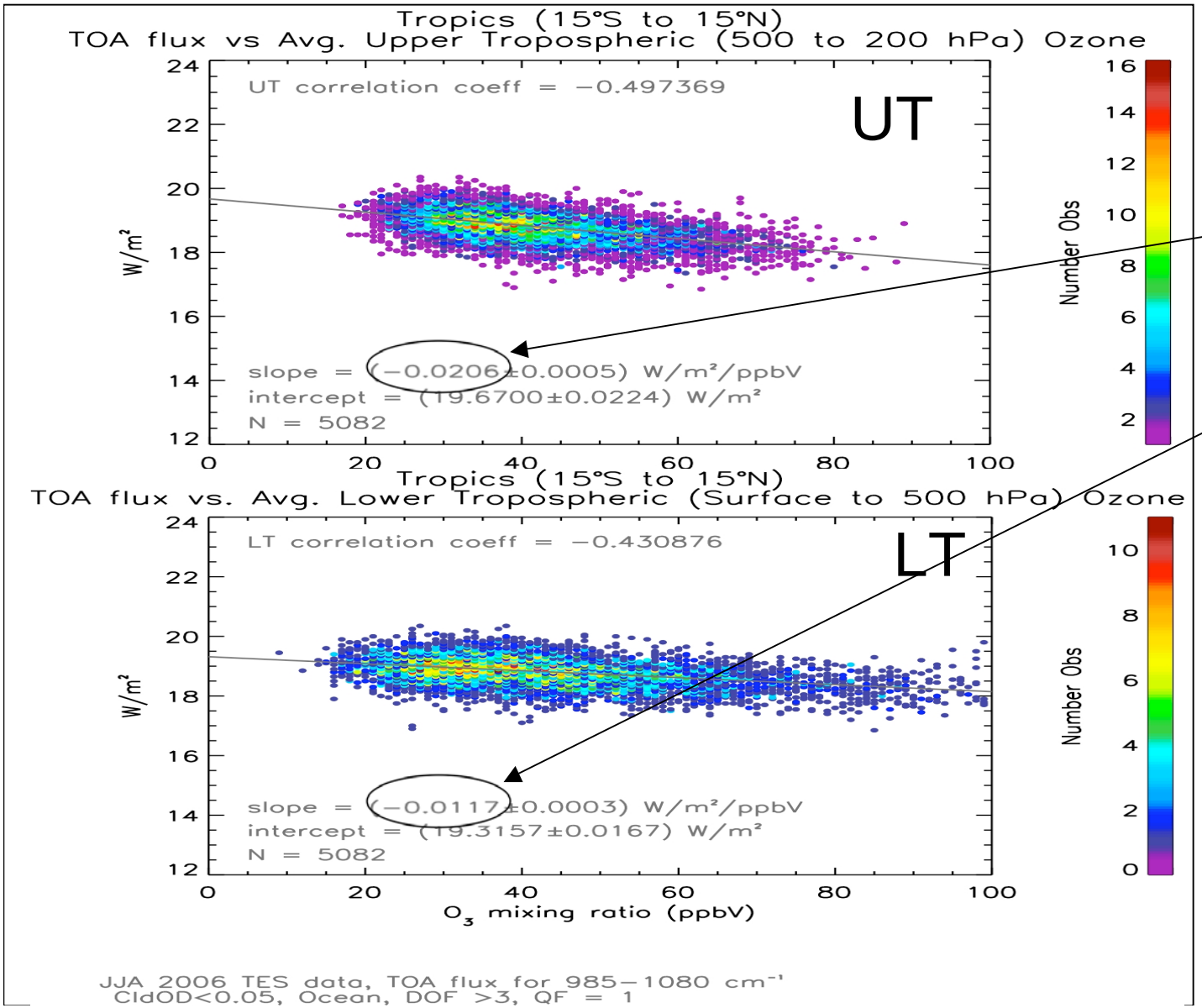
Tropospheric Emission Spectrometer

TOA flux vs. UT and LT ozone in Tropics



UT ozone has stronger greenhouse effect than LT. (slope more negative)

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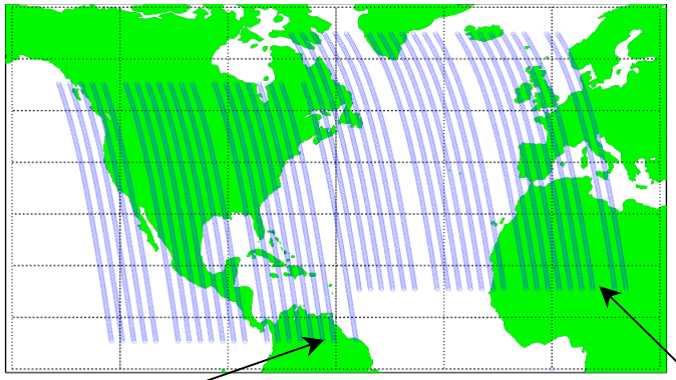
Tropospheric Emission Spectrometer

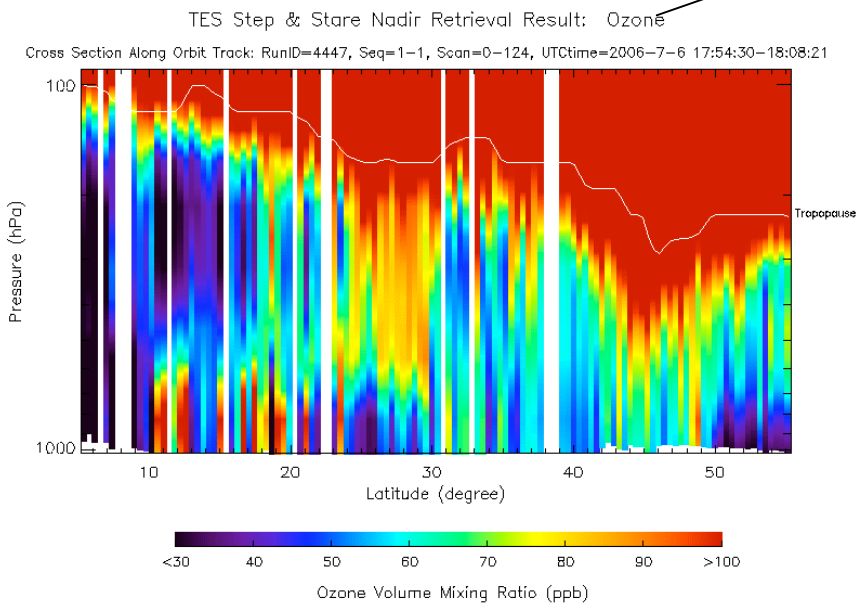
TES Special Observations, Summer 2006

Coverage of TES step and stare special observations for North America to Europe from 4 July to 21 Aug, 2006. Each track was repeated 3 times over the 48 day period.

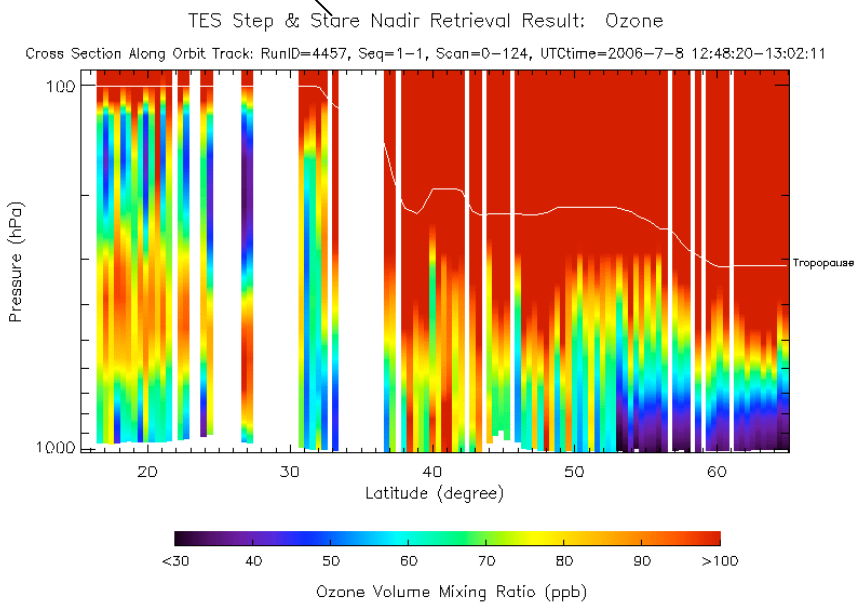


Step/Stare footprints:
~0.4 deg = 45 km apart

Global Survey footprints:
~1.6 deg = 180 km apart



July 6, 2006 TES ozone profiles
Atlantic off NA east coast



July 8, 2006 TES ozone profiles
N. Africa and Europe

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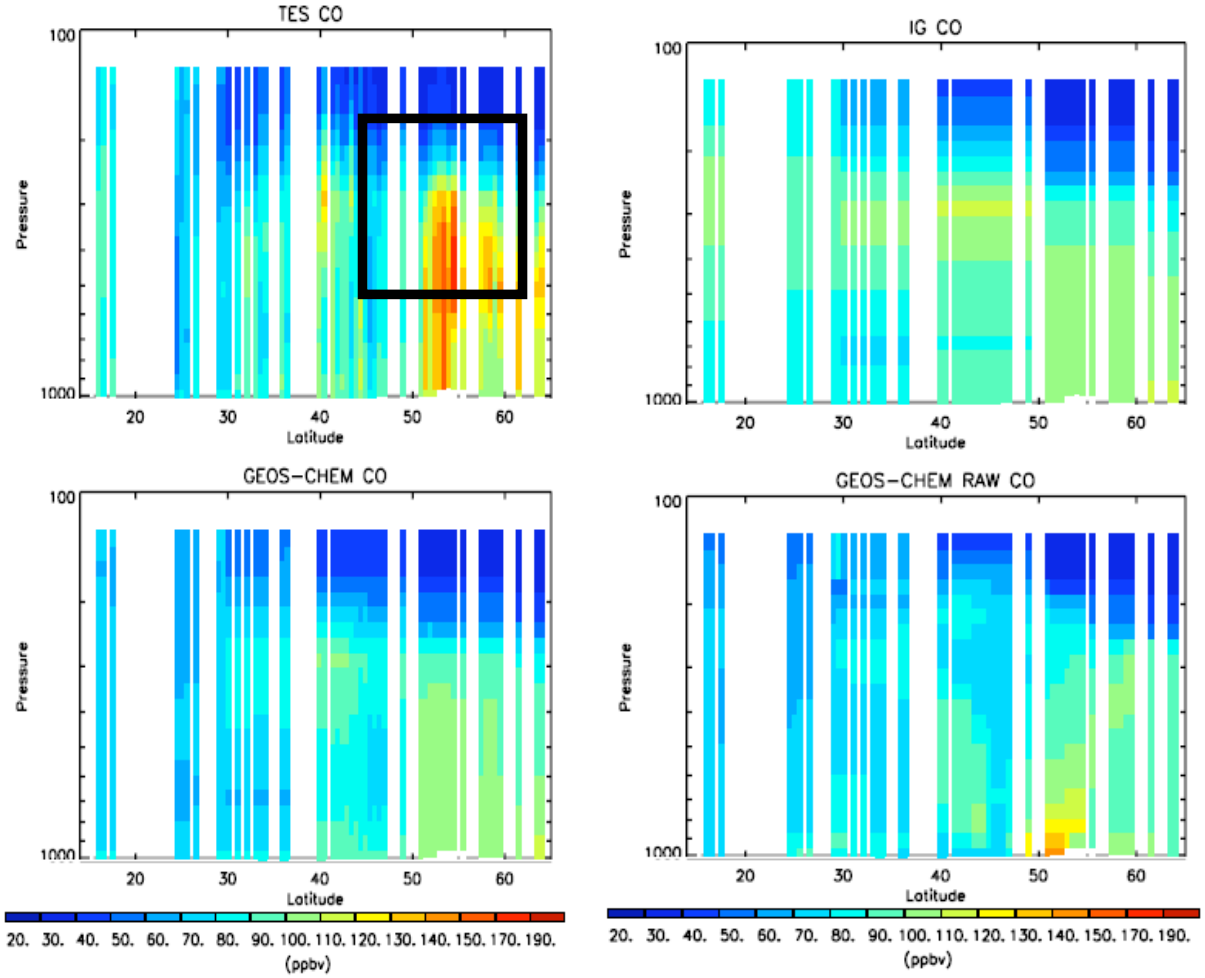
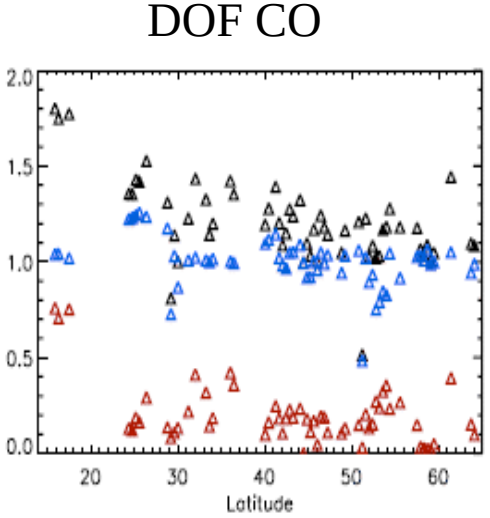
Tropospheric Emission Spectrometer

CO over the North Atlantic (July 8, 2006)





Troposphere

Surface-500hPa

500hPa-tropopause

TES observes CO mixing ratios values typical of the polluted boundary layer over the high latitudes of Western Europe and North Atlantic Ocean in the upper and middle troposphere in July 2006.

L. Jourdain

National Aeronautics and Space Administration
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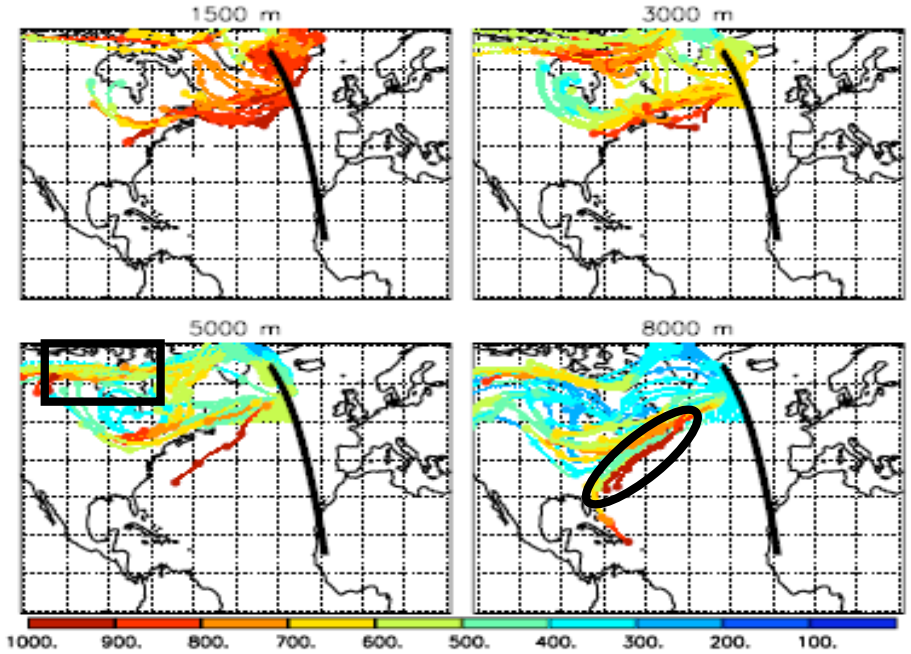
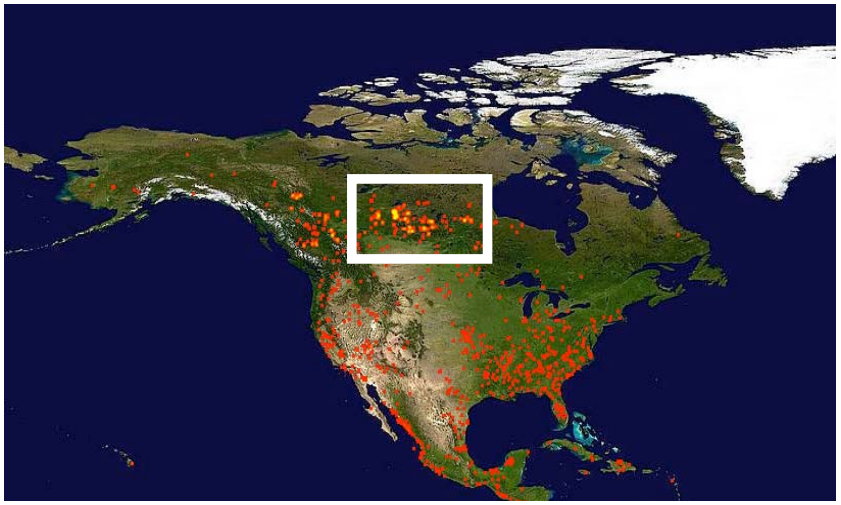
Tropospheric Emission Spectrometer

CO over the North Atlantic (July 8, 2006)

Five-day backward trajectories initialized from the locations and times of the TES Step/Stare targets at 1500, 3000, 5000 and 8000 meters.



MODIS fire counts for the first week of July 2006 .



CO enhancements result from the long-range transport of air masses from the North American boundary layer in particular from the East Coast of United States and from Canada. This suggests the influence of biomass burning over Canada (West of the Hudson bay) in July 2006.

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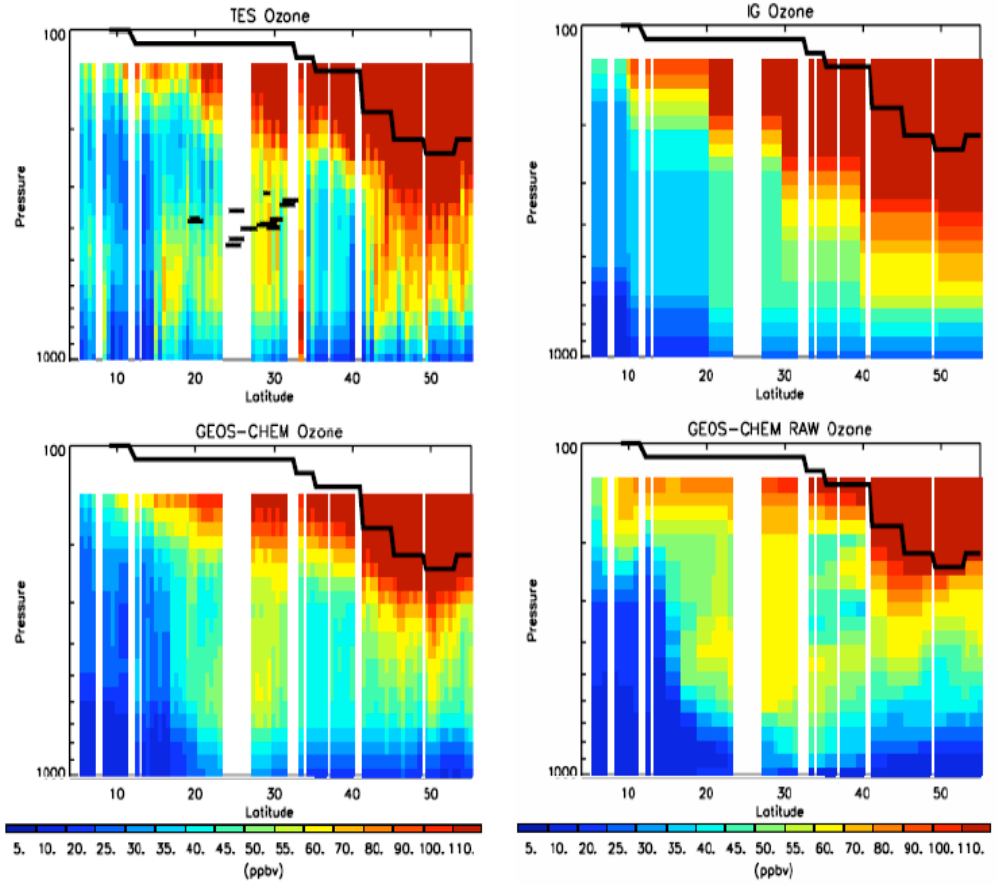
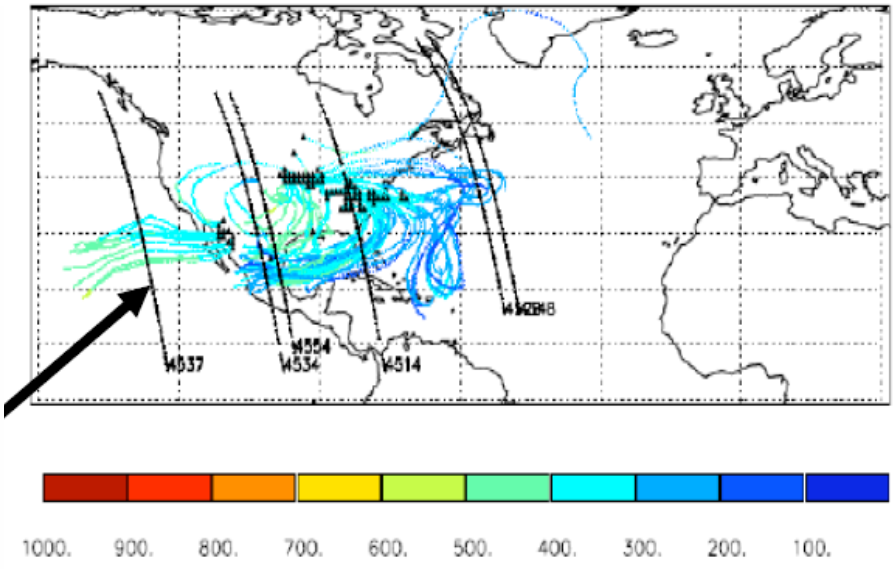
Ozone off the West Coast of North America (July 16, 2006)

Forward trajectories initialized at lightning flash locations (triangles) intersect a TES transect at black dots (below)





TES observes enhanced ozone in the mid-troposphere west of Baja California (black square). This matches with the location of lightning forward trajectories

L. Jourdain

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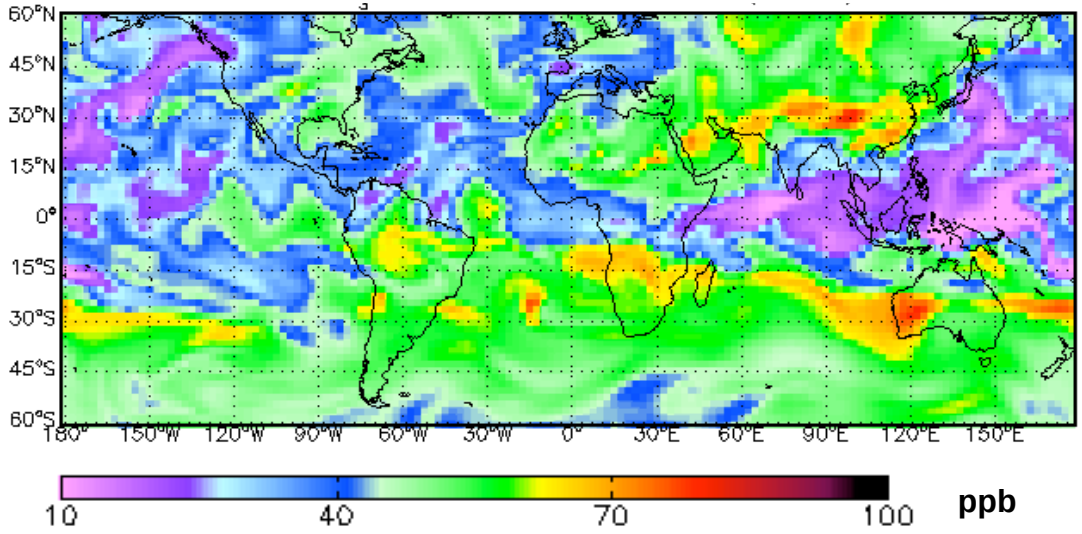
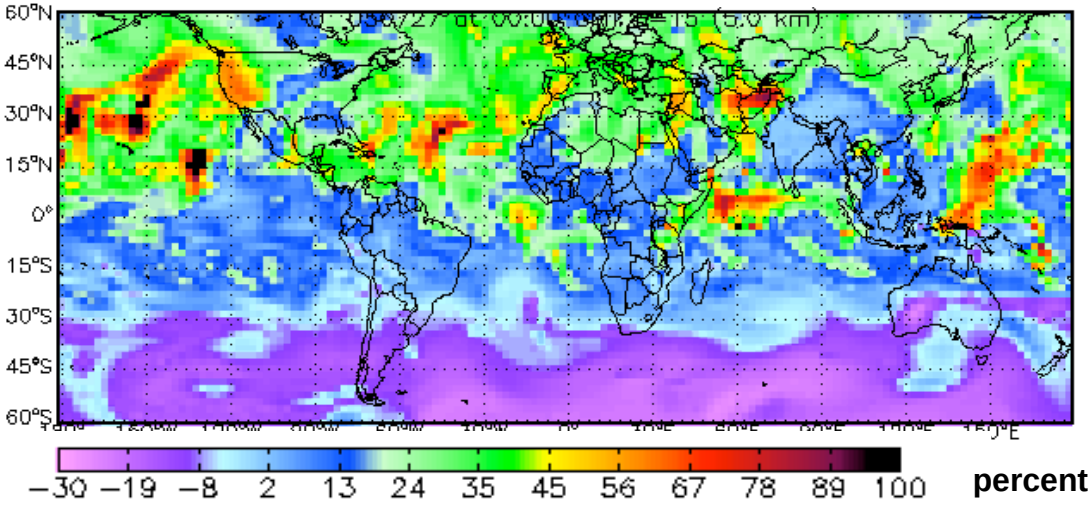
Improving Models of O_3 Chemistry with TES observations

AM2 O_3 at 5 km on 26 July 2005, 0 GMT



Change in AM2 O_3 after assimilation



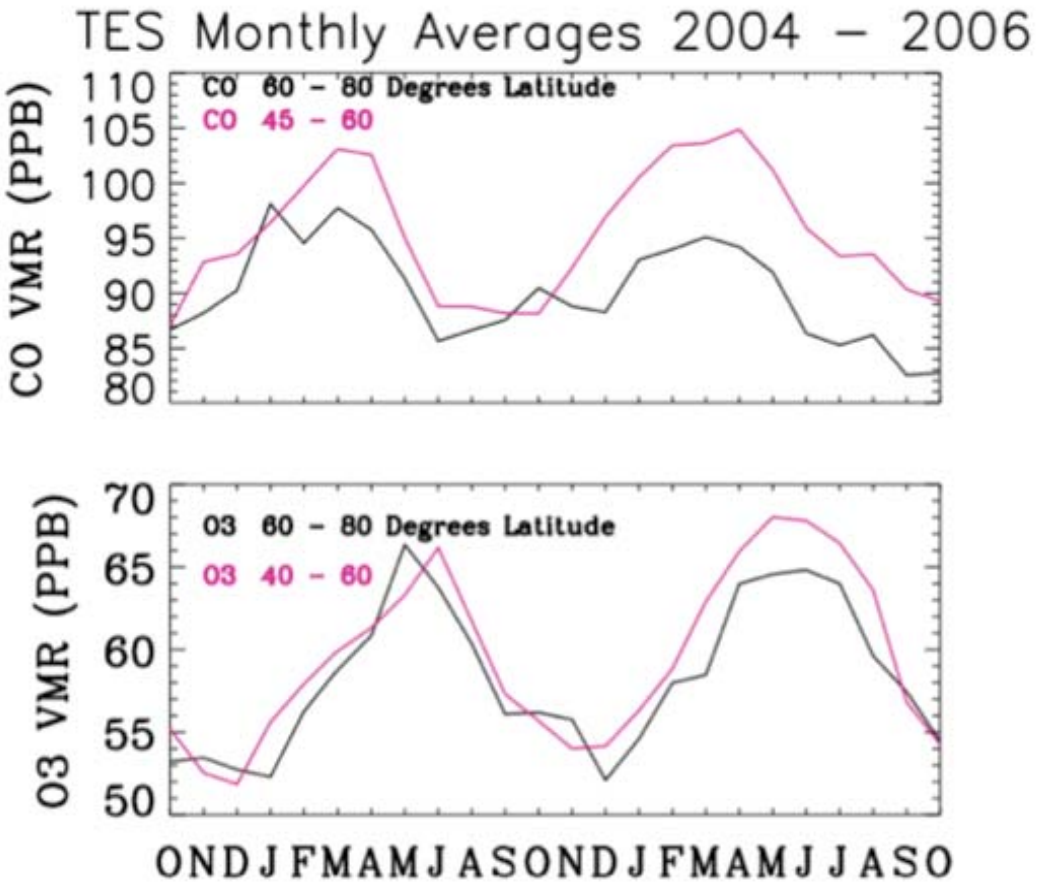
- **Using TES data and other remote sensing data sets to test and improve global models of tropospheric chemistry**
- **Large increases in O_3 (> 25%) in the northern hemisphere in AM2, while O_3 in the southern extratropics in AM2 is reduced by the assimilation**

- **"TES data have sufficient information, when assimilated in a chemical transport model, to dramatically improve the model simulation of O_3, which will enable us to better constrain the different chemical and dynamical processes controlling O_3"**

[Mark Parrington, Dylan Jones, U Toronto]

Arctic O3 and CO

- Analysis of CO and O3 in the Arctic from TES observations
- Shows spring time peak in CO, ozone peak is later ir time
- Strong influence of boreal fires on ozone concentrations
- Additional analysis continues to quantify impact of fires and transport from lower latitudes



Conclusions

- TES is providing unprecedented information about the Earth's lower atmosphere.
- 2.5 years of data, processed consistently, with validated (or provisionally validated) products are available.
  - For links to data go to: http://tes.jpl.nasa.gov
  - User's guide, validation report, readers, and data at Langley DAAC.

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Tropospheric Emission Spectrometer


Tes Team Photo, April 24, 2003

For more info and links to data centers:

tes.jpl.nasa.gov

Back-up Material

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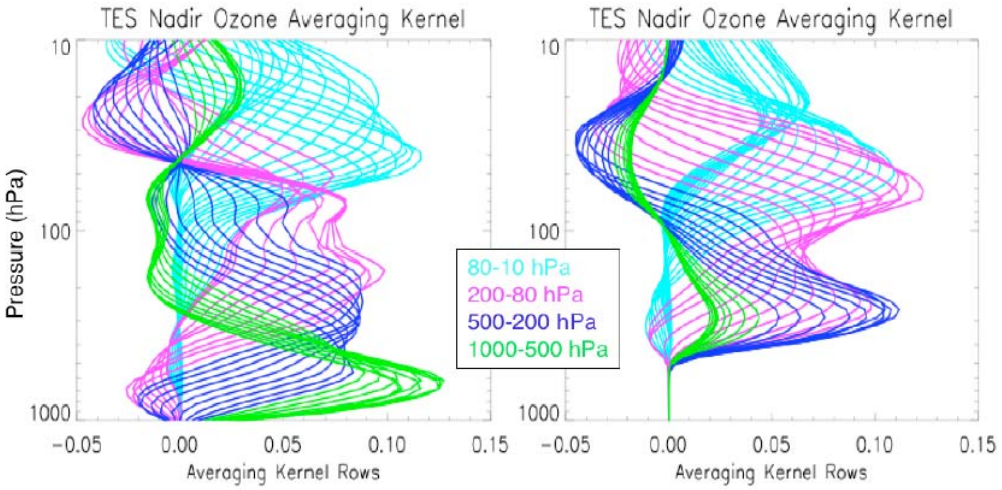
Tropospheric Emission Spectrometer

TES Ozone Averaging Kernels

- Typical vertical resolution for TES ozone is 6-7 km in the troposphere
- The degrees of freedom of signal for the entire ozone profile is between 3-5.
- Averaging kernels provide information on where TES profiles are sensitive and the vertical resolution.
- The averaging kernels also shows how TES sensitivity is smoothed vertically.
  - Information from the stratosphere can have a significant influence on the upper troposphere (blue lines)
- TES retrieves effective cloud properties (OD and cloud top pressure)
  - Retrievals in the presence of thick clouds will appear in AK as no sensitivity (below 500 hPa in right panel)

Tropical
No cloud

N. Mid-lat
cloud at 483 hPa



A. TES measurement near Natal, 9/20/2004

B. TES measurement near Kagoshima, 11/10/2004

See H.M. Worden et al., JGR-Atmospheres, 2006 (in press)

TES Observation Modes

- Standard TES observation mode is the Global Survey
  - The TES GS has changed somewhat over the life of the mission
  - Global Surveys taken Sep 2004 – Apr 2005
    - 73 16-orbit Global Surveys acquired with limb data
    - Nadir targets ~5°apart along orbit track (2 nadir scans averaged)
    - 1152 sequences (2 nadir/3 limb scans)
  - Global Surveys without limb scans started May 2005
    - 3x more nadir targets, ~1.6° separation , no averaging of scenes
    - Limb mode removed from the Global Survey mode to preserve instrument lifetime.
- TES Special Observations
  - Scheduled to support validation campaigns or specific science objectives
  - Transects:
    - Target a set of contiguous scenes (in longitude/latitude)
    - Can be off nadir
    - 40 profiles maximum per TES Run ID covering ~480 km
    - 13 km between profiles
  - Step & Stare
    - Series of nadir scans covering 5700 km along the Aura nadir track (55° latitude)
    - 46 km between profiles

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TES L2 Data Validation Overview

- **TES Version 2 Nadir ozone data show improvements by comparisons to both ozonesondes and lidar.**
- **Carbon monoxide measurements taken after Dec 6, 2005 are significantly improved after an optical bench warm-up.**
- **Validation results for nadir profiles of water, temperature and HDO look promising.**
- **Limb data for nitric acid, ozone and temperature are in the preliminary stages.**

¬ **A summary of the status of TES L2 validation will be provided in the TES L2 Validation Report (v2.0) available (online) in November 2006.**

¬ **TES version 2 nadir data for ozone and carbon monoxide are validated and are appropriate for scientific studies by the atmospheric community.**

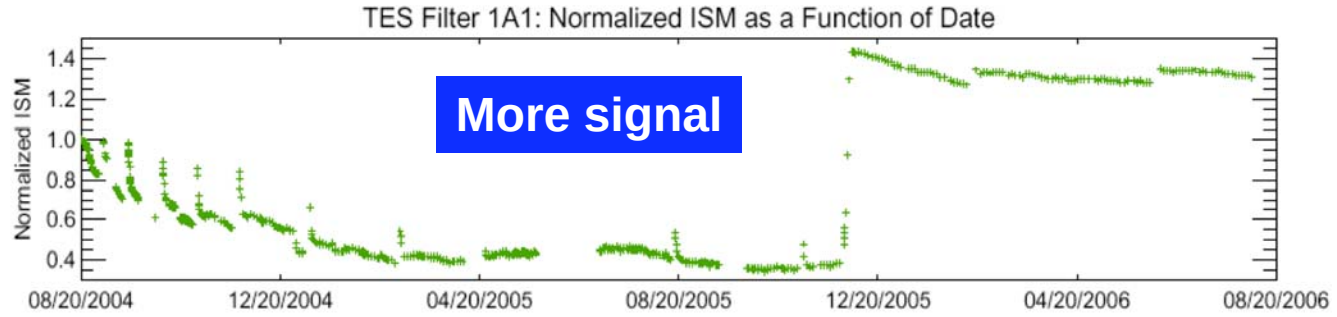
¬ **TES version 2 nadir water, temperature and HDO are provisionally validated and can be used (with caution) for scientific analysis.**

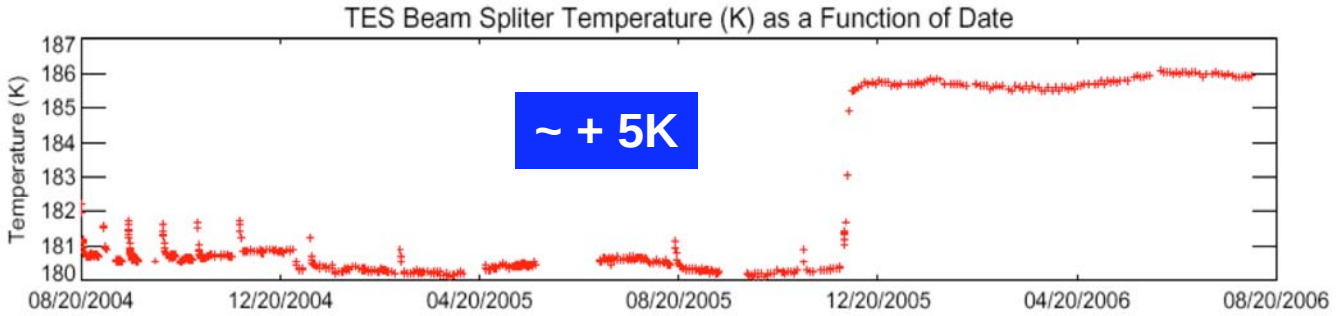
TES L2 Data Products Update

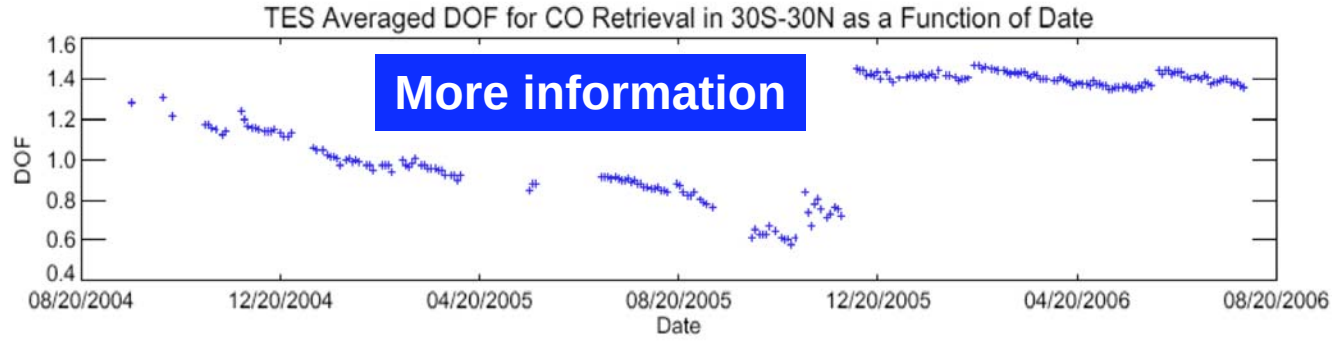
- **TES "Version 2" data have been processed for all TES runs acquired since launch**
  - **All processing goals were met for this version**
- **There are significant improvements over previous versions:**
  - **L1B calibration improved**
    - **differences with AIRS brightness temperatures decreased from ~2K to < 0.5K**
  - **L2 algorithms have been refined**
  - **More extensive quality control information is provided**
- **Version 2 includes HDO as a standard product**
- **Version 2 includes the first limb retrievals**
  - **Stratosphere only for this version**
- **All data are available at the Langley Atmospheric Sciences Data Center (ASDC)**
- **Information on using TES data can be found in the *TES L2 Data User's Guide*, which is available at the Langley ASDC or the TES website.**

Tropospheric Emission Spectrometer

Result of the Optical Bench Warm-Up 12/05







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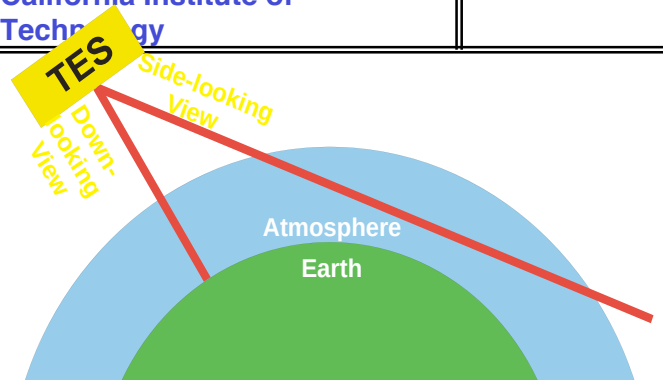
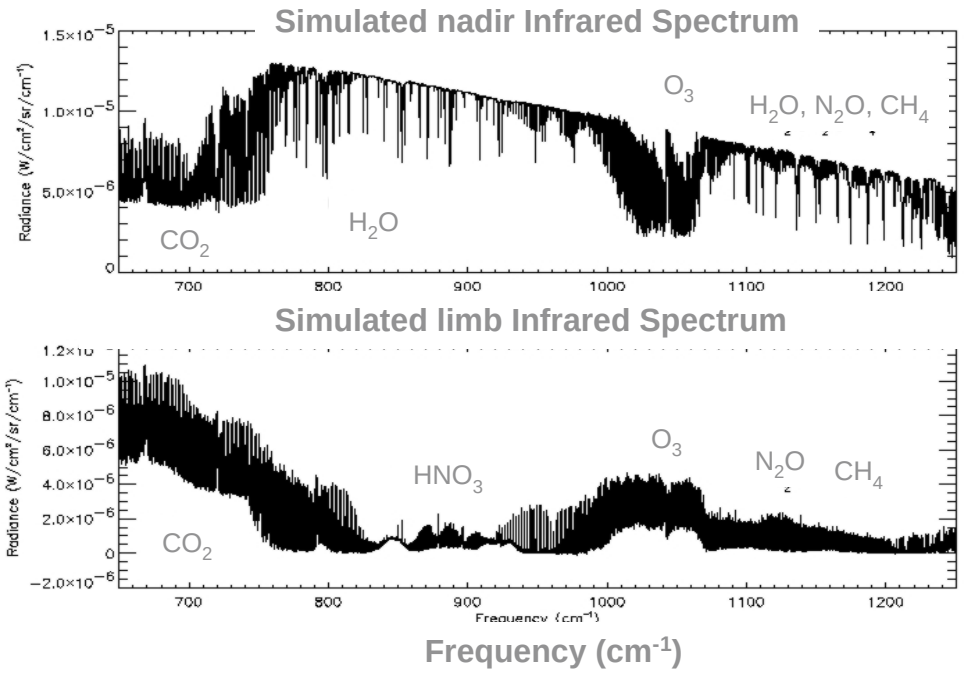
Tropospheric Emission Spectrometer

Driving requirements



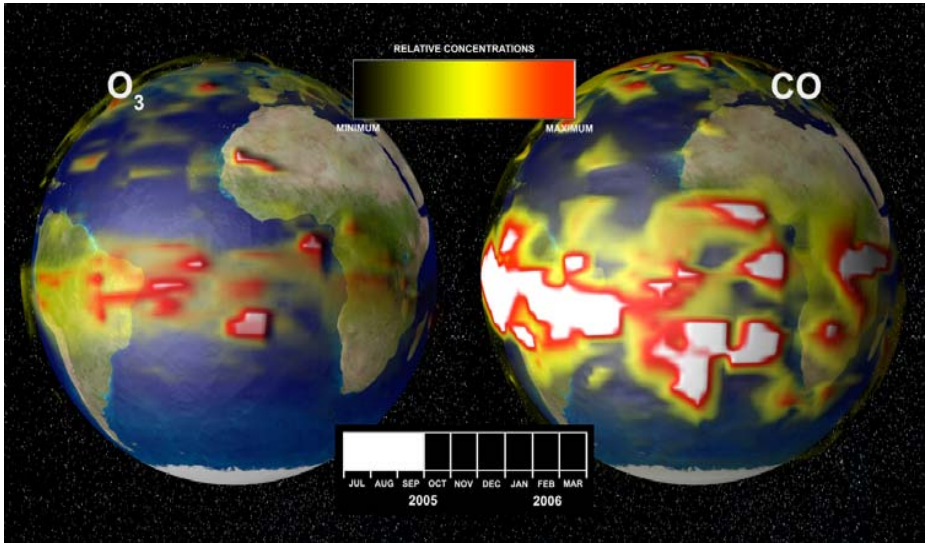


TES Instrument Status

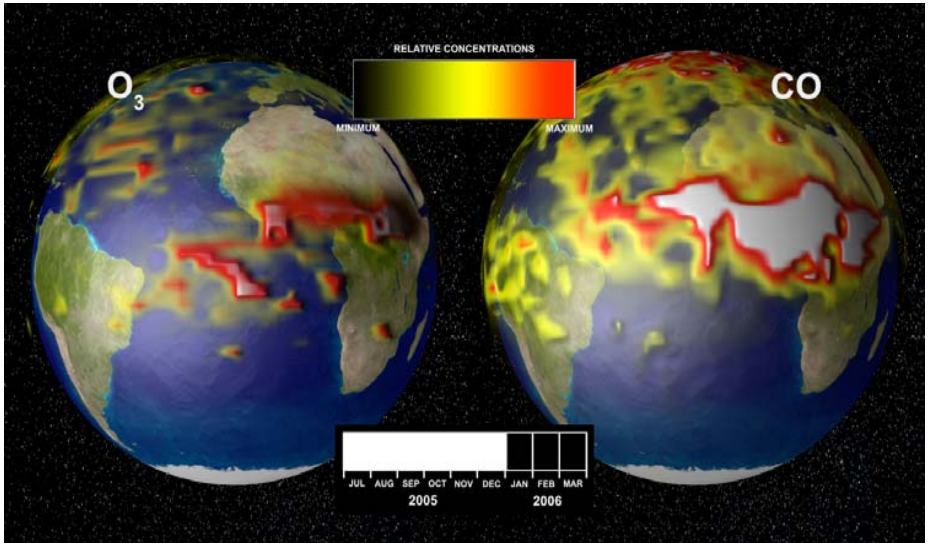
- **TES, with occasional glitches, is working excellently.**
- **The optical bench warm-up in Dec 2005 resulted in a dramatic rise in signal at the shorter wavelengths**
  - **Also improved longer wavelengths, but to a lesser degree**
- **All data are being archived at the Langley DAAC within a few days of receipt at http://eosweb.larc.nasa.gov/PRODOCS/tes/table_tes.html**
  - **as of 12/2006, 312 Global Surveys & 717 Special Observations**

Global Views of Ozone and Carbon Monoxide from TES

Lower troposphere (750 hPa, about 2.4 km)



Signatures of southern hemisphere spring biomass burning.
September 2005.



Signatures of Northern Africa winter biomass burning.
Dec 2005, Jan 2006.